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Alliance Technologies Corp., Bedford, MA

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TECHNICAL GUIDANCE FOR CORRECTIVE MEASURES-- DETERMINING APPROPRIATE TECHNOLOGY AND RESPONSE FOR AIR RELEASES

Draft Final Report

March 1985

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ABSTRACT

The reauthorization of the Resource Conservation and Recovery Act (RCRA) requires that all treatment, storage, and disposal facilities (TSDFs) which apply for a permit which release hazardous waste or constituents from any solid waste management unit at the facility must remedy such release as a condition for permit issuance. The purpose of the guidance document is to assist EPA/State personnel in implementing the new corrective action provisions by providing a central source of information on air emissions control technologies and techniques for hazardous waste TSDFs. This document provides RCRA permit writers with descriptions of waste management unit design and operation practices which prevent or control vapor and particulate releases from containerized waste storage, storage tanks, surface impoundments, landfills, land treatment and waste piles. In addition, control technology transfer from the industrial/commercial sector to the hazardous waste management industry is discussed.

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SECTION 1

INTRODUCTION

BACKGROUND

The 1984 amendments to the Resource Conservation and Recovery Act (RCRA) provide the Agency with additional authorities for corrective action at facilities seeking permits and for facilities with interim status under Section 3005(e). The amendments for corrective action address:

- continuing releases at permitted facilities (Section 206);
- corrective action beyond facility boundaries (Section 207);
- financial responsibility for corrective action (Section 208); and
- interim status corrective action orders (Section 233).

The new authorization allows EPA to require corrective action in response to a release of hazardous waste or constituents from any solid waste management unit to the environment regardless of when the waste was managed. This authority includes releases to all media, including air.

Currently, there are no regulatory requirements for monitoring ambient air surrounding hazardous waste management facilities or emissions from such facilities, or to submit such data with a permit application should the data exist. Thus, the methods available for determining whether air releases are occurring, or can potentially occur, from a hazardous waste management facility are limited to the use of data submitted by the permit applicant.

The Office of Air Quality Planning and Standards (OAQPS) has been given the responsibility for developing regulations for area-source emissions from hazardous waste treatment, storage, and disposal facilities (TSDFs). In this effort, OAQPS is currently evaluating the use of predictive models for quantifying and assessing the health impact associated with TSDF air releases. Due to the current state of development of these efforts and the lack of a substantial base of field validation data, OAQPS has suggested that guidance should be presented in such a way that it can be used as a "flagging tool" for identifying those sites which are obvious contributors of air releases. Once those sites are identified, some type of corrective action or measure will be required to reduce the magnitude of, or eliminate the cause of the air release. As such, the guidance provided in this document identifies the corrective actions and technologies that may be utilized to control air emissions at hazardous waste management facilities.

PURPOSE OF DOCUMENT

The purpose of the guidance presented in this document is to identify corrective actions or specific technologies which will minimize or eliminate the cause of atmospheric releases from hazardous waste TSDFs. Prior to determining the appropriate methods that will minimize the atmospheric release of hazardous waste constituents, the permit writer must first be aware of the types of compounds and facility practices that can potentially lead to ambient air releases. Supported by this background information (which is presented in: "Technical Guidance for Corrective Measures - Identifying Air Releases") the permit application can be reviewed to identify if these compounds and practices of interest are in use at the waste management facility. If identified, corrective measures can then be recommended or required to reduce these air releases.

This document was developed for use as an index of technologies applicable to controlling air emissions from TSDF operations. A large variety of technologies have been described and their effectiveness regarding both cost and reduction of emissions has been evaluated. Various technologies, or combinations of technologies may be applicable to any specific situation. The determination of the most appropriate technology and response will depend on site-specific factors. Consequently, the information presented in this document is general in nature, and the ultimate decision of the appropriate corrective measure to recommend is left to the permit writer.

DOCUMENT ORGANIZATION

Section 2 presents a summary of the corrective measures and technologies for controlling air releases. Corrective measures for certain types of air releases are listed, and technologies are categorized by the specific function that they serve. In addition, a summary of data on cost effectiveness and reduction efficiency is presented.

Sections 3 through 8 present, by facility type, information concerning various methods for controlling air emissions at hazardous waste management facilities. Control technologies for the three facility types which emit primarily vapor phase releases (containers, storage tanks and surface impoundments) are discussed in Sections 3, 4, and 5, while the facility types which have the potential for emitting both vapor phase and particulate emissions (landfills, land treatment, and waste piles) are discussed in Sections 6, 7, and 8. For each of the control technologies which is applicable to a facility type, information is presented to describe the control technology, its particular application to the facility, the cost of the control technology, and its effectiveness in reducing air emissions. Certain control technologies may have multiple applications. In these cases, the technology will be described in detail in the discussion of the first facility type. Reference to the original discussions will be made for subsequent applications.

OTHER GUIDANCE DOCUMENTS

Two additional technical guidance documents will be available for determining the extent which corrective measures for air releases are necessary. These documents published respectively in the spring and summer of 1985 are entitled:

- Technical Guidance for Corrective Measures--Identifying Air Releases; and
- Technical Guidance for Corrective Measures--Assessing Emissions Distribution and Impact.

SECTION 2

SUMMARY OF CORRECTIVE ACTIONS

OVERVIEW

Facilities which propose unacceptable design and/or operating practices, and those that fail to explicitly state these practices, are candidates for corrective measures for reducing air releases. These measures are intended to minimize or eliminate hazardous constituent emissions by correcting an inadequate design or operating practice. The need for, and extensiveness of, corrective measures must be determined on a site-specific basis. Implementation of these measures must take into account the severity of the problem, as well as the location of the nearest receptor. A flow chart outlining the sequence to follow to determine the appropriate corrective measure is presented in Figure 2-1. As is evident, it is first necessary to answer several site specific questions before an effective response can be selected.

EXAMPLES OF CORRECTIVE MEASURES

As shown in Table 2-1, several different corrective measures may be applied to each type of air release. In addition, there may be several specific technologies which can be used to carry out the corrective action. Consequently, the recommendation of a corrective action to limit a particular air release must be based upon the consideration of several alternatives. After evaluating the advantages and disadvantages, the effectiveness, and the cost of each technology, the optimal alternative can be selected.

Table 2-1 presents corrective actions for air emissions by the type of facility at which the air release occurs. One of the most frequently mentioned corrective actions is to cover open or exposed wastes. This type of

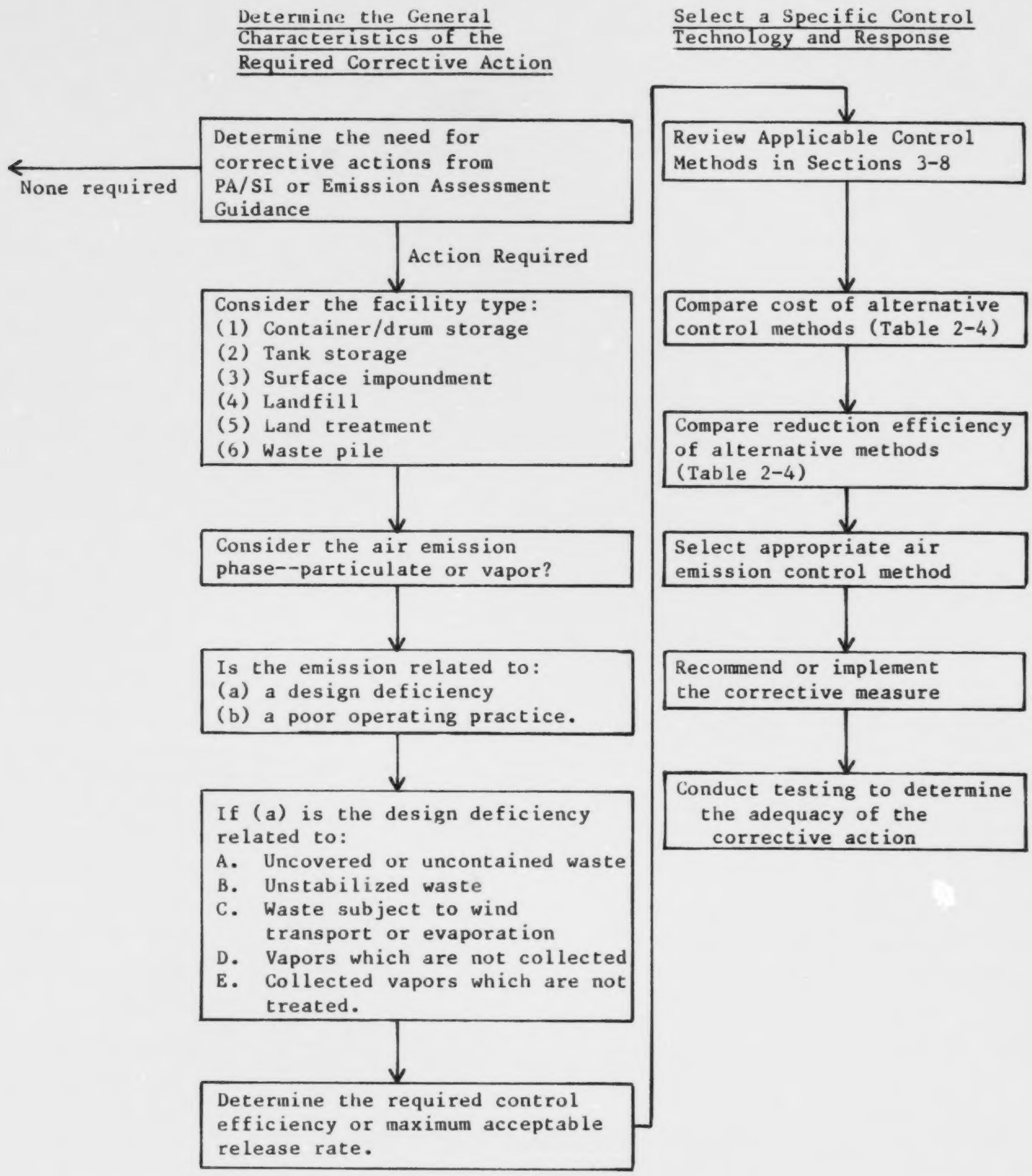
Determine the General Characteristics of the Required Corrective Action
Select a Specific Control Technology and Response
Determine the need for corrective actions from PA/SI or Emission Assessment Guidance
None required
Action Required
Consider the facility type:
(1) Container/drum storage
(2) Tank storage
(3) Surface impoundment
(4) Landfill
(5) Land treatment
(6) Waste pile
Consider the air emission phase--particulate or vapor?
Is the emission related to:
(a) a design deficiency
(b) a poor operating practice.
If (a) is the design deficiency related to:
A. Uncovered or uncontained waste
B. Unstabilized waste
C. Waste subject to wind transport or evaporation
D. Vapors which are not collected
E. Collected vapors which are not treated.
Determine the required control efficiency or maximum acceptable release rate.
Review Applicable Control Methods in Sections 3-8
Compare cost of alternative control methods (Table 2-4)
Compare reduction efficiency of alternative methods (Table 2-4)
Select appropriate air emission control method
Recommend or implement the corrective measure
Conduct testing to determine the adequacy of the corrective action

Figure 2-1. Flow chart for determining an appropriate corrective action.

TABLE 2-1. PRIMARY CORRECTIVE ACTIONS FOR EXAMPLE SOURCES OF AIR EMISSIONS AT TSDFs

Cause of emissions	Applicable corrective actions
DRUM STORAGE	
Liquid leaking from containers and volatilizing	Utilize spill drainage methods: - absorptive floor - grid floor - sloped floor - collection trenches
	Prevent serious leaks by implementing leak detection and repair program.
	Encapsulate container using: - overpacks - directly applied sprays
Container storage without cover or containment structure	Cover container storage area with a synthetic liner.
	Contain storage area in a building or air structure vented to a vapor control system.
Emissions due to environmental factors such as wind, heat, or sun	Use a lean-to-structure to shield containers.
	Use wind screens/barriers.
Splash loading	Utilize submerged or slow filling instead of splash filling.
Spills	Improve drum handling methods: - use drum grabbers - decontaminate drums after emptying
No vapor control during filling/emptying or cleaning operations	Install collection and treatment system.
STORAGE TANKS	
Open top storage tank	Cover tank with: - surfactant layer - plastic spheres - rafts - synthetic membrane - fixed roof - floating roof (internal, external)

(continued)

TABLE 2-1 (continued)

Cause of emissions	Applicable corrective actions
STORAGE TANKS (Cont'd)	
Emissions due to insufficient effectiveness of cover or containment structure	Use alternate type of seal or add secondary seal to floating roof. Use conservation vent on fixed roof. Use alternate synthetic liner material. Use alternate tank design such as converting external floating roof to internal floating roof. Add vapor control system such as carbon adsorption, condensation, or incineration to fixed roof.
Emissions due to environmental factors such as sun or wind	Add thermal insulation to tank walls or cover. Use reflective paint. Employ wind barriers/screens.
Splash loading	Use submerged filling instead of splash filling.
No vapor control during filling/emptying or cleaning operations	Install vapor collection and treatment system.
SURFACE IMPOUNDMENTS	
Open top surface impoundment	Cover impoundment with: - synthetic membrane - floating spheres - rafts - surfactant layer - air inflated structure vented to vapor control system
Emissions due to environmental factors such as sun and wind	Use screens/barriers around perimeter or inside the impoundment. Use shades.

(continued)

TABLE 2-1 (continued)

Cause of emissions	Applicable corrective actions
SURFACE IMPOUNDMENTS (Cont'd)	
Splash loading	Employ submerged instead of surface filling.
Spills, overrun	Increase the freeboard depth by: - physically increasing height of containment - lowering waste level
Disposal by evaporation	Prohibit.
LANDFILLS	
Emission from operating face of landfill	Place temporary wind screens around working area.
	Apply temporary cover material: - synthetic liner - foam - soil
	Enclose work area with air supported structure and employ vapor control system.
Emission through temporary soil cover	Use wind screens in addition to soil cover.
	Stabilize soil cover by: - moisture control (watering) - chemical additives - physical additives
Emission through permanent cover	Decrease permeability of cover by: - using different cover material - vegetating soil cover - moisture control (watering) - adding chemical/physical stabilizers

(continued)

TABLE 2-1 (continued)

Cause of emissions	Applicable corrective actions
LANDFILLS (Cont'd)	
Emission through permanent cover (cont'd)	Add vapor collection and treatment system: - pipe vents with either forced or unforced collection - trench vents (forced/unforced)
Co-disposal of municipal and hazardous waste	Prohibit.
Emissions due to solidification of liquids in situ	Eliminate practice. Enclose operating area and employ vapor control system.
LAND TREATMENT	
Pooling of liquids due to surface application of wastes	Use subsurface injections instead of spraying or overland flow. Decrease the application rate. Dewater waste prior to application.
Emissions caused by environmental factors such as sun or wind	Cover waste with: - soil and employ moisture control - synthetic covers Use wind screens/barriers.
Open treatment area	Enclose treatment area with air structure and employ vapor control system.
Co-disposal of municipal and hazardous waste	Prohibit.
Spray Evaporation	Prohibit.
WASTE PILES	
Open waste piles	Cover with flexible liner (tension structure). Enclose in rigid dome structure.

(continued)

TABLE 2-1 (continued)

Cause of emissions	Applicable corrective actions
WASTE PILES (Cont'd)	
Emissions due to environmental factors such as wind or sun	Use wind screens. Change pile orientation Stabilize dust with: - water application - chemical additives - vegetation Reduce the slope of the pile.
Fugitive release due to uncontrolled loading	Use alternate loading practices to lessen particle generation: - hinged boom conveyors - telescopic shutes - stone ladders

measure is effective by providing a barrier to the unrestricted volatilization of hazardous waste constituents. The type and extent of the cover needed is dependent on the waste characteristics and the type of facility at which the cover will be used. Liquid wastes containing volatile organic compounds have a high emission potential and require a more permanent and secure cover (e.g., floating roof) than a solid waste with few volatile components. For instance, a waste pile may require only a portable synthetic cover to minimize both vapor and particulate releases during its active life.

Changes in facility operating practices, namely those associated with the emptying, filling, or cleaning of containers, and the loading or applying of waste to landfills, wastepiles and land treatment facilities are another means of providing corrective action. A common method of reducing emissions that result from the filling of tanks, surface impoundments, or drums is to employ submerged filling, as opposed to splash loading. Submerged filling minimizes liquid surface turbulence, a factor which contributes to air releases. Similarly, at land treatment facilities, use of subsurface injection in place of spreading or pouring waste on the soil surface reduces the time and area of waste contact with the atmosphere.

Treatment processes that are designed totally or in part, to provide for the release of airborne contaminants as a way of reducing the solid or liquid phases contaminant level should not be allowed. Practices such as disposal by evaporation and co-disposal of hazardous and municipal wastes, in which significant quantities of hazardous constituents may volatilize or evaporate are two examples of such unacceptable practices. The purpose of these practices is to promote evaporation and airborne release of the contaminants and no change in the practice or add-on control equipment can change this intent. Consequently, these practices should be prohibited.

Types of Corrective Actions

The two general types of corrective actions mentioned above and presented in Table 2-1 are design or operational. Design measures are those that limit the ambient emissions due to the intrinsic design of the waste management hardware or the installation of air emission control devices. Operation corrective actions minimize emissions by controlling the manner in which the waste is handled. Design practices can further be broken into groups based upon the function that the specific design practice serves. These groups are:

- containment
- insulation
- stabilization
- gas collection
- vapor control

Containment--

The purpose of containment is to minimize the surface area of the waste which is exposed to ambient air. This function is served by enclosing or covering the facility or waste in some manner. The containment structure can either be supported or be placed directly on top of the waste surface. For example, a temporary cover may either be placed directly on the solid surface of an active landfill or it may be supported above the waste. Supported and unsupported structures are separated since supported containment generally involves a much greater amount of construction or alteration than does unsupported containment. For example, unsupported containment measures, such as floating spheres and rafts, can simply be placed on a liquid surface of a tank or impoundment, while a fixed roof or dome requires significant design and construction to implement.

Insulation--

Methods of insulation serve to lessen the rate of air emissions by specifically reducing the effects of wind and sun. Covers may also have this effect, although they are primarily designed to enclose the waste and not specifically to protect it from environmental factors. This type of corrective action can generally be added on to the existing structure or facility without changing the existing structure to a great degree.

Stabilization--

Stabilization is used to reduce particulate or volatile emissions from the waste itself or to improve the performance of a cover material by making the cover less permeable and/or more stable. Stabilization usually involves the addition of a chemical, or other material, to the facility or its contents.

Gas Collection--

The installation of gas collection systems at a TSDF may require that extensive alterations be made if the system is added to an existing facility. The effort required to retrofit an existing facility is dependent on the facility type. For instance, the addition of a collection trench vent system to a system will involve excavation, while the addition of a conservation vent to a fixed roof will not require as extensive an effort. In any case, these types of controls are more easily applied if incorporated into the original design of the facility.

Vapor Control--

Vapor control or treatment is generally used in conjunction with some type of containment structure and gas collection system. The cover serves to channel the air pollutants to the collection device which then vents the pollutant to a vapor control unit. The vapor control unit then serves either to destroy the pollutant, as in fume incineration, or to merely remove it from the gas phase as in adsorption or condensation. Vapor control systems act not to prevent volatilization from occurring, but to treat the emissions once they have occurred.

In Table 2-2, each of the types of air emission control methods discussed above is listed, with the type of facility to which the control can be applied. Certain technologies, such as the vapor control methods, apply to all of the facility types, while others, such as subsurface injection, only apply to one of the facility types. Only those controls which have a high probability of application to the specific facility type are checked; those controls which only have a very low potential of being applied have not been checked.

In addition to the corrective actions listed in Table 2-2, there exist several general classes of corrective actions which may be applicable on a site specific basis. These measures include pretreatment of the waste, consideration of alternate disposal options, and post-treatment.

Waste pretreatment refers to actions that reduce the air release potential of the waste by removing the hazardous constituent of concern. Examples of pretreatment include, but are not limited to:

TABLE 2-2. AIR EMISSION CONTROL TECHNOLOGIES/TSDF--MATRIX

	Drum storage	Tank storage	Surface impoundment	Landfills	Land treatment	Waste piles
CONTAINMENT						
Supported						
Air inflated structure	X	X	X	X	X	X
Building	X	X			X	X
Dome		X				X
Fixed roof		X				
Floating roof		X				
Unsupported						
Clay/soil cover				X	X	X
Immiscible film		X	X			
Inert gas blanket		X				
Floating spheres		X	X			
Floating rafts		X	X			
Synthetic membrane				X	X	X
Foam				X	X	X
Drum encapsulation	X					
OPERATING PRACTICES						
Subsurface injection					X	
Submerged filling		X	X			
Spill/leak control	X	X	X	X	X	X

(continued)

TABLE 2-2 (continued)

	Drum storage	Tank storage	Surface impoundment	Landfills	Land treatment	Waste piles
Increase freeboard depth			X			
Less frequent filling/ emptying	X	X	X			
Decrease application rate					X	
Controlled loading				X	X	X
Moisture control				X	X	X
STABILIZATION						
Wet dust suppression				X	X	X
Vegetation				X		X
Encapsulation	X			X		
Chemical dust stabilization				X	X	X
INSULATION						
Wind screens/Barriers	X	X	X	X	X	X
Shades	X	X	X			
Thermal insulation	X	X				
Painting	X	X				
GAS COLLECTION						
Pipe vents				X		
Trench vents				X		
Gas extraction				X		X
Conservation vents		X				

(continued)

TABLE 2-2 (continued)

	Drum storage	Tank storage	Surface impoundment	Landfills	Land treatment	Waste piles
VAPOR CONTROL						
Adsorption	X	X	X	X	X	X
Fume incineration	X	X	X	X	X	X
Condensation	X	X	X	X	X	X
SPILL CONTROL						
Foam	X	X	X	X	X	X
Water dilution	X	X	X	X	X	X
Adsorbents	X	X	X	X	X	X
Coolants	X	X	X	X	X	X

- Distillation
- Steam or air stripping
- Adsorption
- Ozonation
- Wet oxidation
- Chemical oxidation
- Biological oxidation
- Physical separation

These technologies are standard waste treatment technologies, which when applied to a waste will reduce the hazardous constituents of concern.

The use of an alternate disposal option can be an appropriate corrective action if the air release potential of the waste cannot be minimized using the more conventional (and less expensive) techniques previously described. For example, elimination of a waste containing volatile organic constituents by incineration may be the most effective manner to reduce the emission potential of the waste.

Post-treatment measures refer to those actions that are taken to insure that the constituents emitted from the waste (gaseous or particulate) are captured and effectively disposed so as not to result in an emission from the facility. For instance, with regard to vapor collection systems on storage tanks, captured organic vapors are condensed and returned to product storage or disposed of in a manner that precludes their emission. Similarly, fugitive particulate, once captured, must be handled and disposed so as to minimize the potential for reentrainment.

Because pretreatment, alternate disposal, and post-treatment methods involve action to the waste which would be conducted either previous or subsequent to their management at the TSDF in question, they will not be further addressed in this document. The permit writer need only be concerned with recommending practices which could be implemented on site.

FACTORS TO CONSIDER IN SELECTING CORRECTIVE MEASURES

A major factor to consider when recommending a particular corrective action is the severity of the emission. Some releases may require major or emergency steps to be taken, while others will only require simple or minor steps to be taken. Other factors to consider include the effectiveness of that action in controlling air emissions, and the cost that is associated with implementing the action. These two factors together can be combined to evaluate the overall cost effectiveness of the corrective action. Each of these factors is discussed below.

Severity of the Air Release--

The severity of an air release is based on the potential for endangering human health and the environment. If it is determined that an unacceptable risk is posed by some activity, then an immediate and possibly major corrective action will be required. Conversely, if there is only a low potential for toxic air emissions due to some poor design or operating practice, the corrective action required may be less extensive in nature. As seen in Table 2-3, the difference in the actions required for an emission of minor or significant levels of concern is primarily based upon the level of the air release. The difference between the actions required for an air release of significant and major levels of concern, however, may necessitate an entirely different sort of action, generally much more severe.

Cost--

The capital cost associated with each corrective action or technology will depend on several factors. The major costs are those associated with materials and equipment themselves, and those associated with the construction or installation of the materials and equipment. The cost of some technologies will be almost solely a function of the cost of materials, while the cost of others will be predominantly installation costs. An example of the former is the placement of floating spheres or rafts on the surface of an impoundment or tank. An example of the latter is the covering of a surface impoundment or other facility with an air supported structure. For example, if a surface impoundment of 60,000 ft^2 is to be covered by rafts, the cost will be approximately $6,000. (Refer to Table 2-4). Conversely, the cost of installing an air supported structure for this size impoundment will be approximately $400,000. This difference in cost is primarily a result of the difference in installation cost.

Other factors, however, must be considered in addition to the capital cost of the corrective action. There are advantages and disadvantages of the

TABLE 2-3. PROBABLE CORRECTIVE ACTIONS AS A FUNCTION OF THE LEVEL OF RELEASE

	Level of release		
	Minor	Significant	Major
Cause:	- Toxic volatile or particulate wastes managed with poor design and operating conditions	- Toxic volatiles and/or particulates present in populated areas with no controls - Highly toxic wastes managed	- Unacceptable risk determined due to activity; toxic volatiles present and emitted either by evaporation or mobilization by CH_4 or CO_2
Corrective Action:	- Dust suppression - Cover drains and sumps - Install spill collection system - Cover waste piles with liner (small piles) - Cover landfill (small) - Submerged filling instead of splash filling - Monitor - Fixed roof and vapor control on open top tank (small units).	- Dust suppression, capture and collection - Vapor collection and disposal - Cover waste piles with liner (large piles) - Fixed roof and vapor control on open top tanks (large units) - Enclose drum storage area with vapor collection and disposal - Cover landfill (large)	- Prohibit disposal by evaporation - Prohibit co-disposal of hazardous wastes with municipal wastes

TABLE 2-4. COST AND REDUCTION EFFICIENCY OF AIR EMISSION CONTROL TECHNOLOGIES

Technology	Cost ($)[a]	Efficiency (%)	Comments
Supported Containment			
Air-inflated structure	400,000	High (>90%)	A. D. Little, 1984; total installed cost of system over 425 x 150 ft lagoon. Including carbon adsorption vents.
	+100,000 ($6-9/ft^2 of floor space)		A. D. Little, 1984; total installed unit costs; does not include treatment system costs.
Building	67,150	80-99 (with treatment)	SCS, 1983; for drum storage with capacity of 33,120 ft^3.
Dome	49,000-54,000	95-100 (particulate) 85-95 (vapor)	Vogel et al., 1983; installed cost for waste pile storage dome with diameter of 61 ft, capacity 1150 tons.
External floating roof tank	53,000-280,000	62-99[b]	EPA, 1980; cost of whole tank 30-100 ft diameter.
Contact internal floating roof with primary seal	7,450-55,000	88-99[c]	EPA, 1980; cost of roof, 15-90 ft diameter, plus seal.
+ secondary seal	15.68/ft circumference	40[d]	EPA, 1980.
Noncontact internal floating roof with primary seal	6,000-40,000	88-99[c]	EPA, 1980; cost of roof and seal 15-90 ft diameter.
+ secondary seal	30/ft circumference	60[d]	EPA, 1980; cost of wiper seal.
Fixed roof	34,000-354,000	90[b]	EPA, 1980; cost of whole tank 20-90 ft diameter.
	109,000		Vogel et al., 1983; 25 ft diameter 50,000 gallon tank.
Unsupported Containment			
Soil covers	11.20-17.20/yd^3	50-100	EPA, 1982; costs range depending on whether clay or topsoil is used; includes hauling, spreading, compaction.
Synthetic covers	3-26/yd^2	90	EPA, 1982; installed cost of various materials from 20 mil PVC to Teflon-coated fiberglass.

(continued)

TABLE 2-4 (continued)

Technology	Cost ($)[a]	Efficiency (%)	Comments
Unsupported Containment (Cont'd)			
Tension structure	4.30-6.50/ft^2 of surface area	95-100 (particulate)	Vogel et al., 1983; synthetic membrane with auger feed system.
Foam cover	0.11/ft^2	N/A	Vogel et al., 1983; cost of 2-inch layer of urea-methane foam.
	4,350		One-man application system.
Immiscible film	0.03 cents/ft^2	25-75	Vogel et al., 1983; cost of hexadecanol monolayer.
Floating spheres	4.65-8.69/ft^2	80-90	A. D. Little, 1984; costs depend on sphere size.
Floating rafts	0.05-0.13/ft^2	80-90	A. D. Little, 1984.
Inert gas blanket	0.11-0.33/gallon capacity	50-99	Vogel et al., 1983; annual cost of nitrogen blanket system; efficiency when used with insulation and conservation vent.
Drum encapsulation	65-90/drum	99	EPA, 1981; fiberglass-lined and welded systems.
	26-40/drum		Directly applied system.
Operating Practices			
Subsurface injection	100,000-160,000	30-90	Vogel et al., 1983; subsurface injection vehicle.
	5,500-8,700		Tool bar filled to existing surface application vehicle.
Controlled loading	10,500	75	Bohn et al., 1978; telescopic chute used for steel industry waste piles.
	30,000	80	Stone ladder.
Leak detection and repair	200-3,000/unit	NA	Cost of monitors, both portable and fixed.
Drum handling equipment	300-600/unit	NA	Cost of drum grabbers.
Submerged filling	NA	NA	Depends on construction requirements.

(continued)

TABLE 2-4 (conntinued)

Technology	Cost ($)[a]	Efficiency (%)	Comments
Operating Practices (Cont'd)			
Decreased application rate	NA	NA	Low cost, but increased area will be required for same waste production.
Increase free board depth	NA	11-80	Costs are low depending on whether liquid surface is lowered or berm height is increased.
Change waste pile orientation	0	NA	Vogel et al., 1983.
Improved cover practices	NA	90	A. D. Little, 1984; moisture control of landfill covers.
Stabilization			
Wet dust suppression	NA 90,000	50 (particulate) 75 (particulate)	Efficiency based on Rosbury, 1985. Bohn et al., 1978; water spray system used at steel industry waste piles.
Vegetation	1,550/acre	NA	R. S. Means, 1984; hydroseeding.
Encapsulation/ solidification	100-850 $/ton of waste	NA	EPA, 1982; low cost for lime, high for organic polymer.
Chemical dust stabilization	80-1,350/acre	80/100 (particulate)	Drehmel et al., 1982; cost depends on specific chemical used.
Insulation			
Wind barriers	0.04-0.23/ft^2	11-80	A. D. Little, 1984; cost for styrofoam barriers 1-4 inches high in varying grid patterns; based on surface impoundment area.
Wind screen	14/lineal foot	0-30 (particulate)	Vogel et al., 1983; cost based on 6 ft high fence.
Shades	0.07-0.18/ft^2	26-44	A. D. Little, 1984; black woven polyethylene shade cloth.

(continued)

TABLE 2-4 (continued)

Technology	Cost ($)^a	Efficiency (%)	Comments
Insulation (Cont'd)			
Thermal insulation	0.05-0.76/in.-ft^2	50-99^e	Vogel et al., 1983; polyurethane coating; efficiency when used with conservation vent.
Reflective paint	500-3,000/tank	25	Petroleum storage facility estimate.
Gas Collection			
Pipe vents	1,450/unit	70-90	EPA, 1982; cost of 4-inch pipe vent, 30 ft deep with forced ventilation.
Trench vents	330,000	70-90	EPA, 1982; total cost of 20 ft from vent, 4 ft wide, 1,500 ft long with a hypalon liner; excavation is 80 percent of total cost.
Gas extraction	17,000-40,000	70-90	SCS, 1983; cost range for 2,000-100,000 ft^3 waste pile and includes carbon adsorption system.
Conservation vents	0.01-0.09/per gallon capacity	50-90	Vogel et al., 1983.
Vapor Control			
Carbon adsorption	1,100-1,600/tank	85-97	Vogel et al., 1983; unit cost for large system.
	670-920/unit		Calgon Corporation; cost for "barrel" system.
Fume incinerator	7,500-11,000/tank	85-99	Vogel et al., 1983; cost for 50,000 gallon tank.
Condensation	11,000-16,000/tank	85-95	Vogel et al., 1983; cost for 50,000 gallon tank.

(continued)

TABLE 2-4 (continued)

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[a] Costs are all updated to March 1985.

[b] As added to open tank (A. D. Little, 1984).

[c] As added to open tank (EPA, 1980).

[d] Increase in efficiency due to addition of secondary seal.

[e] When used in conjunction with a conservation vent (Mitre, 1983).

References:

Arthur D. Little, Inc., EPA-450/3-8/017. November 1984.

Bohn, R., et al., EPA-600/2-78-050. March 1978.

Calgon Carbon Corporation, Sales Literature, March 1985.

Drehmel, D., et al. Relative Effectiveness of Chemical Additives and Windscreens for Fugitive Dust Control. February 1982.

R. S. Means, Inc. Building Construction Cost Data. 1983.

SCS Engineers. Interim Report on Air Emissions. September 1983.

USEPA. EPA-450/3-80-034a. December 1980.

USEPA. EPA-600/2-81-138. July 1981.

USEPA. EPA-625/6-82-006. June 1982.

Vogel, G. A. and D. F. O'Sullivan. Air Emission Control Practices at Hazardous Waste Management Facilities. June 1983.

specific technologies which may negate any cost advantage of one technology over the other. One of the major factors, of course, is the amount of air emission reduction which can be achieved. Air emission reduction using floating rafts has been estimated to be from 80 to 90 percent while the reduction associated with using an air inflated structure can be greater than 90 percent. In some cases, the added reduction efficiency may justify the added cost.

The cost data which is presented in Table 2-4 is based both on literature and on current quotes provided by vendors. Literature cost estimates have been updated to March 1985 using the Engineering News Record construction cost index. Comments are used to explain exactly what the listed cost includes or what it is based on. In addition, to obtain more detailed costs, one should refer to the section in which the particular technology is discussed. These cost data are intended to be approximate in nature, and actual costs will depend on site specific factors. The costs indicated should provide the permit writer a basis for a rough comparison of the cost of implementing alternative corrective actions.

Effectiveness--

The percent reduction or control efficiency percentage attributed to a certain technology is defined by the following relationship:

$$\text{Control efficiency} = \frac{\text{uncontrolled emissions} - \text{controlled emissions}}{\text{uncontrolled emissions}} \times 100$$

The controlled and uncontrolled emissions are usually expressed as a rate and not as the total mass emissions.[1] Reduction efficiencies for a variety of control technologies are presented in Table 2-4. The purpose of a corrective action can in some cases be to control volatile emissions, while in other cases the action is implemented to control particulate emissions. It should be noted that the technology efficiencies provided in Table 2-4 are for vapor phase releases. However, certain technologies may be applicable for both vapor and particulate control. In these cases, technology efficiencies have been provided for both phases. In general, if a technique can mitigate vapor releases, it should be capable of controlling particulate releases at least as effectively.

The total control efficiency of corrective actions can be the result of implementing several control schemes in series. For example, the control efficiency of a gas collection system at a landfill will be a function of the combined efficiencies of a trench vent, a cover material, and possibly a vapor treatment system. If the collection system does not include an effective cover material and lateral barriers, the vapors will not be collected in the vent, and the control efficiency of the system will be correspondingly decreased.

Another example of this involves the addition of a secondary seal to a contact internal floating roof with a primary seal. In Table 2-4, the listed efficiency of this action is 40 percent. This increase in control is over and above the 88 to 99 percent efficiency attributed to the internal floating roof with just a primary seal. In other words, if the primary control has an emissions reduction efficiency of 88 percent, the installation of an add-on secondary control with a 40 percent control efficiency will provide a combined efficiency for the total system of 93 percent $(0.88 + (0.12 \times 0.40))$. Consequently, when evaluating the effectiveness of a corrective action, the combined effects of several technologies may need to be considered.

Very few of the control efficiency estimates listed in Table 2-4 are based on measurements carried out at actual TSDFs. Consequently, the level of certainty of these estimates as applied to TSDFs is unknown. However, they can be used as general indicators of reduction efficiency. Field testing of the corrective actions will verify the correctness of these estimates. For example, one recent study[2] investigated the effectiveness of wind screens in reducing particulate emissions from waste piles. The findings indicated that, contrary to previous hypotheses, a reduction in wind speed does not necessarily result in a commensurate reduction in particulate loss from the pile. Consequently, reduction efficiencies which had been based on wind speed have been lowered to the values presented in Table 2-4.

In general, reduction efficiencies attributable to supported containment structures and vapor control systems are very high (>90 percent), while those attributable to various other design and operational practices are variable and range from zero up to 99 percent. As mentioned previously, however, many corrective actions which may not reduce emissions by more than 90 percent, may still be worth implementing due to their low cost. These include operational practices such as submerged filling, moisture control for landfill covers, and unsupported containment designs such as placing floating spheres, rafts or immiscible films on open surface impoundments and tanks.

REFERENCES FOR SECTION 2

1. Vogel, G. A., and D. F. O'Sullivan. Air Emission Control Practices at Hazardous Waste Management Facilities. MTR-83W89. Prepared for U.S. Environmental Protection Agency, Office of Solid Waste. Contract No. 68-01-6092. The MITRE Corporation. McLean, VA. June 1983.

2. Rosbury, K. D., and J. C. James. Control of Fugitive Dust Emissions at Hazardous Waste Cleanup Sites. Draft Report sent to M. Arienti, GCA Corporation. March 1985.

SECTION 3

CONTROL OF EMISSIONS FROM CONTAINERIZED WASTE

INTRODUCTION

Hazardous waste material placed into containers can include both liquids and solids. The material is put into containers either at the generator site or at the TSDF. Containers used for this purpose may be either closed or open-top, and loading may be done by either splash or submerged filling techniques.

For the purpose of discussion, this section will focus upon waste material held in steel 55-gallon drums. Releases from containerized wastes occur primarily as a result of leakage or accidental spillage. Control options available to facilities which handle, store, or dispose of containerized wastes may be classified as follows:

- storage modifications;
- spillage containment;
- container modifications; and
- operating practices.

Table 3-1 provides an overview of the advantages and disadvatanges of control alternatives described in this section. This section will develop and describe technology options provided in Table 3-1 under each of these classifications. Example systems will be cited, and relative effectiveness (emission reduction- and cost-) will be presented for each.

TABLE 3-1. ADVANTAGES AND DISADVANTAGES OF CONTAINERIZED WASTE EMISSION CONTROL ALTERNATIVES

Advantages	Disadvantages
Storage Modifications	
● Can achieve high emission reduction efficiency. ● Insulates containers from external forces which exacerbate emissions. ● Will not affect containers or waste materials. ● Various designs available, thus can be applicable to any facility. ● Will not affect the operation of the facility. ● Better suited (than other options) for larger facilities.	● High implementation costs involved. ● Implementation is constrained by requirements of location, layout, and manpower. ● Does not increase response time to spill or leak. ● Maintenance costs will rise. ● May require handling of contaminated materials.
Spillage Containment	
● Reduces emissions, and possibility of reemission by isolating spilled substances from the environment. ● Provides rapid mitigation of spill emissions. ● Well-suited to random spill incidents. ● Applicable to spills occurring both on land and water.	● Emissions reductions achievable are not high. ● Facilities which handle many different types of waste substances may need to implement many different procedures, thus increasing expense. ● Requires additional handling of hazardous or volatile materials.

(continued)

TABLE 3-1 (continued)

Advantages	Disadvantages
Spillage Containment (Cont'd)	
● Technologies are readily transportable, thus are applicable to any size facility. ● Manpower required, in general, are low. ● Materials needed, in general, are inexpensive and can be obtained easily by a facility. ● Application methods are relatively simple and implementation of such procedures will be easy. ● Costs, overall, are expected to be low for such procedures.	● Requires disposition of contaminated materials. ● Possible side effects (e.g., seepage of chemicals into ground) may limit applicability. ● A certain percentage of spills may not be manageable at all due to volume or location. ● Costs are subject to variations in materials costs.
Container Modification	
● Highly effective in reducing emissions from containers--most effective of all technologies described in this section--due to mitigation of both spills and container breathing losses. ● Increases safety of container handling procedures. ● Permanent system--prevents further incidents. ● Applicable to prevention of both chemical and mechanical stresses from both within the container and externally.	● Requires additional equipment, manpower, and materials. ● Total costs to implement systems may be high. ● Costs may be particularly high for facilities which would need to encapsulate a great many drums. ● May require handling procedures to be altered. ● Drums would not be reusable.

(continued)

TABLE 3-1 (continued)

Advantages	Disadvantages
Container Modification (Cont'd)	
● Insulates container from thermal fluctuations as well as mechanical shocks.	
● Technology allows for transport to various points around facility.	
● Applicable to range of container sizes.	
● Materials required are relatively easily obtainable.	
Operating Practices	
● Reduces leaks and spills, the major contributor to containerized waste emissions.	● Emission reductions achievable are low.
● Does not change or affect containers or waste.	● May affect overall operation of facility (input/output considerations, for example).
● Increases safety at facility.	● May be less effective as number of drums increase at a facility.
● Applicable to any drum handling, disposal, or storage facility.	● May not be well suited to highly volatile or toxic substances.
● Very easy to implement procedures at an existing facility.	● Requires additional manpower and/or equipment.
● Accomplish emissions control quickly--either by preventing emission from occurring or by rapid response to spill or leak.	● Implementation may be limited by accessibility of containers.
● Generally are low in total costs.	

STORAGE MODIFICATIONS

Introduction

Drum storage areas range in sophistication from simple, outside, uncovered areas with no leakage or spillage containment, to fully enclosed buildings which are evacuated and serviced by a vapor control system (e.g., carbon adsorption). Modifications to storage areas are classified as any physical change in the area. This subsection will focus on three modification options, which are as follows:

- Troughing/spill drainage;
- Wind deflection; and
- Building containment

All three of these options are used extensively at both TSDFs and industrial processing plants.[1]

Description

Because emissions from containers occur largely as a result of volatile waste materials spilling or leaking from containers,[1] all modifications are intended either to reduce environmental factors such as wind and solar irradiation, or more effectively manage spilled or leaked material so that emissions can be limited. Emissions which occur due to container "breathing" are expected to be mitigated by storage modifications, as well. In selecting the modification option which is most applicable to a specific TSDF, the following considerations must be made:

- Location of storage area. Whether the containers are stored outside or inside, or where the storage area is in relation to other parts of the TSDF.
- Available area. The storage area may be constrained in terms of height, layout, and other space restrictions.

- Storage procedures. By virtue of which waste materials are being stored, or how a facility is equipped to handle their waste containers, the procedures by which the facility places containers into and removes containers from storage.
- Type of containers being stored. Whether containers are open-top or enclosed.
- Number of containers being stored. The number of containers to be stored, and the frequency with which they are brought in and taken out of storage.

The three modification options which are most applicable to TSDFs based upon the above criteria, and which, therefore, are the most commonly employed designs found in industry, are described below.

Troughing/Spill Drainage--

Troughs, grid floors, and other similar modifications serve to contain emissions by channeling spilled (or leaked) materials away from the containers, so that spills can be cleaned up more efficiently and effectively. Most storage facilities should employ a drainage system of some kind. Implementation of these systems is applicable to both outside and inside storage areas. Examples of this type of modification include:

- perimeter trench or trench network;
- sloped floor;
- absorptive floor; and
- grid (screen) floor.

These systems may not be applicable to facilities which employ certain storage procedures.

Trench System--A system of trenches can range in sophistication from a simple moat around the perimeter, to a series of interconnected channels within the storage area. The primary design features to be considered in selecting the most appropriate trench system are trench depth and trench system layout. The trenches may, in addition, be lined with a synthetic membrane, or filled with absorptive material.

Sloped Floor--A sloped floor can be formed either by reconstructing an existing floor, or installing a new floor. The primary design features to be considered for this type of system are slope, permeability, and weight handling requirement.

A sloped floor could also be coated in some way, e.g., a polyurethane sealing compound, or could incorporate a trench system. The most common types of sloped floor are those constructed of concrete. Concrete floors are especially suitable for outside storage areas.

Absorptive Floor--An absorptive floor is a simple system in which an absorbent material covers either the entire floor area or just under where the containers will be placed. By placing drums directly on top of the absorbent, leaks can be handled immediately, and clean-up procedures may be simplified greatly. The primary design features to be considered in establishing such a system are the type of absorbent material selected (must be chemically compatible with waste materials), the depth of the absorbent layer, absorbent layer layout (related to traffic patterns), contaminated absorbent handling procedures, and layer regeneration. Such systems may also incorporate synthetic membranes or other leachate handling systems.

Grid Floor--A grid, or screen floor is a simple system in which drums are placed on a screen which is raised above the actual floor level. This type of system allows spilled material to drop to the floor, thus separating the spill from the drums. The primary design features to be considered in this type of system are screen type (grid size, weight handling capacity, and screen material), screen floor layout, distance between screen and floor, and waste handling procedure. Screen floor systems might be expected to employ a layer of absorbent material placed directly under the screen. The screens themselves may be coated, to prolong their usable life.

Wind Deflection--

Various systems designed to deflect the flow of wind away from waste-containing drums are used. These controls are applicable only to outside drum storage. Considerations involved in selecting the appropriate system are:

- Type of barrier. Options include (and are not limited to) cyclone fences, picket fences, corrugated steel walls, or cinder block walls.
- Height of barrier. The higher the barrier is, the more wind is reduced. Higher barriers, however, must also be stronger structurally.
- Materials of construction. Materials must be chosen with an emphasis on low costs. The effect of chemical degradation must also be considered.
- Storage area arrangement. By compartmentalizing, the effectiveness of a barrier is increased. Compartmentalizing, however, necessitates the use of more fencing, and makes the logistics of the storage area more complex.

Examples of wind deflection systems include:

- simple perimeter system, and
- "compartmentalized" system.

Perimeter Wall--Perimeter walls are the most common type of wind deflector system.[3] The primary design features to be considered in establishing a perimeter wall system are the height of the wall and the type of wall selected. The wall may be designed to vary in height according to expected wind patterns.

Compartmentalized System--A compartmentalized system serves to bring the nearest wall closer to each drum, thus increasing the effectiveness of the wall. A wide variety of designs are available, ranging in sophistication from randomly spaced sections to a "honeycomb" complex. The primary design features to be considered in these systems are wall height and type, system layout, and area access and egress. Such a system would allow a facility to segregate wastes, access the area from different points, and install covers on certain parts of the areas while leaving others uncovered.

Building Containment--

An enclosed structure will serve to contain emissions by providing a more controlled environment for the drums and the waste material they contain. The effects of wind, solar irradiation, and precipitation can be reduced significantly if not eliminated completely. A building containment can be more effective in reducing emissions than any other modification to an outside storage area.[4] A building containment can be equipped with various appurtenances such as vapor control systems, or can be built with multiple levels to provide more storage per area. Examples of building containment designs which might be selected are:

- lean-tos; and
- free standing structures.

Building containments may be limited in applicability by various location or area considerations.

Lean-tos--A lean-to is a simple structure, commonly built onto the side of an existing structure. While in general a lean-to is constructed using simple materials, these systems can range in sophistication from a simple roof shade to a fully enclosed and insulated structure. The primary design features to consider in selecting the most appropriate lean-to are storage space needs, storage procedures, and construction materials.

Free-standing structures--A facility may choose any number of designs for a free-standing structure. Among the many design features to be considered are: available area, building layout (including decision to make multiple levels), appurtenances (insulation, vapor control, etc.), and storage procedures.

The relative ease or difficulty of implementing modifications to storage facilities is dependent upon the unique constraints of each particular system and application. In general, installation of troughs or wind deflectors can be accomplished with less cost and effort than construction of buildings. This is due to the space and materials requirements involved, and also due to the difficulties associated with construction at hazardous waste facilities.

Emission Reduction Effectiveness

Modification of the drum storage area is expected to yield moderately high emission reductions. The availability of information on the efficiency, however, is limited. No studies of such controls have been published in the literature. Of the three modification categories described in this section, building containment is expected to effect the highest reductions. A study of air emissions done by SCS Engineers estimated that building containment can achieve from 80 to 99 percent emission reduction.[4] The effectiveness of a wind barrier is directly proportional to its height (the effectiveness at any point is dependent on the ratio of barrier height to the distance from the base of the barrier to that point). One study estimated that windscreens at waste piles can reduce wind erosion by an average of 80 percent.[2]

Costs

Modifications to the storage area are expected to vary in cost, depending upon the design features selected. Costs are based upon construction labor and materials, and operating materials requirements. There is no energy or operating labor cost involved, and maintenance costs are assumed to be relatively insignificant. Detailed information on the control systems described in this section is not available. In general, troughing/spill drainage modifications are expected to cost less than wind barriers, which in turn are expected to cost less than building containments.

The costs of a spill drainage system was estimated by SCS in 1983 for a system involving a concrete floor with curbs and gutters (a 1200 square foot area of 6 in. thick sloped concrete pad with perimeter curbs and gutters).[4] This system is estimated to cost $5,200 in current dollars (March 1985).

The same study by SCS estimated that a fencing system consisting of a 6-foot high, 6 gauge galvanized industrial chain link fence with 2-inch line posts and 10-foot 1-5/8 inch top soils and three strand barbed wire; two 15-ft wide gates; and four 3-ft wide gates[4] would cost $16,600 (in March 1985 dollars) for an area of 9000 ft^2 (capable of holding 100 drums).

A building containment system was estimated by SCS for a structure of 33,120 cubic feet.[4] In present value, the cost is estimated to be $68,000 for the building alone.

SPILLAGE CONTAINMENT

Introduction

Because the air release of hazardous constituents from containerized wastes is largely attributable to leaks and spills of volatile hazardous materials, those techniques established for containing, collecting, and removing spilled material represent a significant area for emission control. Spills of waste from containers generally occur during drum handling (moving) operations, and to a lesser extent during drum loading operations. Leakage from containers occurs primarily during storage and disposal. At present, the various spill control techniques in use are limited in their applicability.[5] The methods of controlling the vapor release of spills can be generalized as belonging to one of the following categories:[6]

- control by mechanical means;
- control by chemical means; and
- control by use of physical properties of the spilled substance.

Description

All spill control procedures incorporate the following elements:

- isolation of spilled substance;
- coverage of spilled substance;

- absorption of spilled substance; and
- removal of spilled substance and contaminated materials.

The methods by which substances are absorbed and removed are standard throughout the industry. This subsection will focus on procedures to isolate and cover substances. In selecting a spill containment option, the following considerations must be made in determining the applicability of the option.

- Type of material spilled. Chemical compatibility, volatility, or physical properties of the spilled substance.
- Amount spilled. Whether a great deal of material must be contained or only a small amount.
- Manpower and/or materials requirements. A facility needs to consider the personnel or equipment capacity necessary.
- Spill location. Where a certain substance is spilled in relation to other parts of a TSDF.

The three categories of spill containment options each include procedures which satisfy much of the above criteria. The most commonly used procedures are described below.

Control by Mechanical Means--

By placing a barrier between the hazardous material and the environment (atmosphere), the release of volatile material can be hindered or eliminated.[6] Similar control technologies have been applied for control of emissions from surface impoundments. A mechanical barrier is applicable to most spills. Examples of this type of system are:

- tarpaulin or synthetic membrane; and
- foam cover.

A mechanical barrier may be limited in applicability due especially to chemical compatibility or spill volume.

Synthetic Membrane/Tarpaulin--A synthetic membrane or tarpaulin is generally a simple sheet (blanket) which would be spread out over the spill. These systems have been used extensively in industry.[6] The primary design features which must be considered in selecting the most appropriate membrane cover are the size of the cover, resistance to chemicals, transportability to spill location, and spreading technique. These covers may be treated with special coatings. They may be packaged in certain ways (e.g., parachute covers) which make for more facile usage. They may also be made from either flexible or rigid materials.

Foam Cover--There are a wide variety of foams which have found application for spill control, including protein foams, surfactant foams, and alcohol-based foams.[5] Foams are used extensively for application in fire-fighting[8] and in control of natural gas spills. A foam blanket acts both to isolate the spill from the atmosphere and sources of radiant energy, and to either absorb the chemical or dilute the surface layer of the spill. A foam cover can be used to control both landborne and aqueous spills of volatile compounds.[5] The primary design features to be considered in selecting foam cover systems are the type of foam, the foam application process required, and the handling of contaminated foam.

Control by Chemical Means--

By addition of selected chemicals to the spill, the physical or chemical form of the spilled material may be altered, thus reducing the volatility of the material.[6] Chemical addition is applicable to many landborne spills, but in most cases may not be used for aqueous spills. The two most common methods employed are water dilution and chemical neutralization.

Water Dilution--Water may be applied to spilled materials in a variety of ways, including as a spray or mist, or by simply flooding. Dilution with water is the most common method employed for mitigation of spills.[6] The water acts as a diluent and/or a dispersant. The primary design features to consider in selecting the water dilution system to be implemented are availability of water supply, chemical compatibility of water with spilled materials, water application procedure, and seepage control.

Chemical Neutralization--Chemical neutralization agents are available in various forms including foams, powders, and liquids.[8] Neutralization is a fairly common spill control procedure.[6] It is applicable to most spills. The primary considerations involved in selecting an appropriate neutralization system are chemical compatibility, waste neutralizability (hazardous waste materials tend not to be consistent in their properties, and thus a certain "kind" of waste may not always be neutralized by a certain agent), application procedure, and neutralization agent storage and handling procedures (the agents themselves may be hazardous in nature).

Control by Use of Physical Properties--

By altering the conditions affecting the spill, it is possible to utilize the physical properties of the spill to control vaporization.[6] Among the physical properties that might be taken advantage of are the sorptability, and vaporization point temperature. The most commonly used control options of this type are thus absorption and cooling.[7]

Absorption--A wide variety of materials may be used as an absorbent, including straw, charcoal, mulch, flour, or one of the many commercially available sorbents.[6] Absorption is, therefore, used extensively as a spill containment alternative. The sorbents can be kept readily available. The sorbents can be applied when needed either by hand or spray gun. Sorbents are applicable to any spill situation. The primary design considerations to be made in selecting an appropriate absorbent are type of materials spilled, application method, and contaminated sorbent handling and disposal.

Cooling--Many different cryogenic materials are utilized to reduce the temperature of a spill such that the volatility of the material is reduced, including ice, dry ice, liquid CO_2, and liquid nitrogen.[7] Cooling has not found wide application in spill control, although it is used in conjunction with other procedures (cooling increases control effectiveness). Coolants are generally applied by spraying over the spill. The primary considerations involved in selecting a cooling system are coolant type and availability, chemical compatibility, and coolant storage procedure.

Spill control procedures are very simple to implement. Most do not require complex application procedures or equipment. Relative to other container emission control options, spillage containment are perhaps the easiest to implement at a TSDF.

Emission Reduction Effectiveness

Spillage containment technology is considered to be a relatively effective means of controlling emissions from spills of containerized waste. As summarized in Table 3-2, ratings based upon field evaluation of control technologies have been developed. Table 3-2 shows that certain technologies, in particular foam covers and water dilution, are moderately to highly effective in reduction of emissions.

Mechanical covers (synthetic membranes and foam covers) have been assessed in a number of EPA documents. Synthetic membrane covers, which are similar to the covers used for surface impoundment emission control described in Section 5, have been estimated by MITRE to be up to 90 percent effective for emission control from surface impoundments.[2] The effectiveness of such systems applied to spill control may be somewhat less, due to lower scale application. In general, the effectiveness of synthetic membrane covers relates to the vapor permeability of cover materials (see Table 4-2 in Section 4) and the effectiveness of enclosure. Foam covers used for spill control were assessed in detail by Gross and Hiltz.[5] A summary of their findings is presented in Table 3-3, and is detailed below:[5]

1. High quality foams which have low drainage, i.e., retain their water content, performed the best in mitigating the vapors during spill control tests.
2. For nonpolar liquids, any high quality foam cover, regardless of its chemical type, will provide some degree of mitigation of vapor release.
3. Only alcohol foam was stable against hjighly polar low molecular weight liquids such as acetone. Other types of foam rapidly collapsed.
4. The vapors from polar spills may be mitigated with nonalcohol type low expansion foams if the volume of foam is several times greater than the volume of the spill. This reduction is mainly due to water dilution rather than a foam cover.

TABLE 3-2. RATING OF EFFICIENCY OF CURRENT RESPONSE TECHNIQUES TO CONTROL EVAPORATION

	Slight reduction	Moderate reduction	Highly effective
Sumping and trenching	x		
Wet Foaming		x	
Deep soil burial			x
Sorbents (straw, mulch, etc.)	x		
Water flooding			x
Dispersants (on thin water layers)	x		

Source: Brown et al., 1981 (Ref. 6).

TABLE 3-3. MATRIX OF FOAM CAPABILITIES TO SUPPRESS OR OTHERWISE MINIMIZE THE RELEASE OF TOXIC OR FLAMMABLE VAPORS FROM SPILLED HAZARDOUS CHEMICALS AS LISTED

		Surfactant foams						
	Recommendation	Low expansion	High expansion	Protein	Fluoroprotein	Alcohol	AFFF[a]	Mech.
i-octane	R	B+	A+	B+	B+	E-	C+	U
n-heptane	R	B+	A+	B+	B+	E-	C+	U
Cyclohexane	R	B+	A+	B+	B+	E-	C+	U
Hexane	R	B+	A+	B+	B+	E-	C+	U
Benzene	R	B+	A+	-	-	E-	ND	ND
Toluene	R	B+	A+	-	-	E-	ND	ND
Gasoline	R	B+	A+	B+	B+	E-	C+	U
Kerosene	R	B+	A+	B+	B+	E-	C+	C+
Naphtha	R	B+	A+	B+	B+	E-	C+	U
Methanol	R	E-	E-	E-	E-	A+	E-	-
i-propanol	R	E-	E-	E-	E-	A+	E-	-
Butanol	R	E-	E-	E-	E-	A+	E-	-
Butyl Cellosolve	ND	ND	ND	U	ND	ND	ND	U
Acetone	R	E-	E-	E-	E-	A+	E-	ND
Methyl Ethyl Ketone	ND	U	U	U	ND	ND	ND	ND
Methyl 1-butyl ketone	R	B+	A+	U	ND	ND	ND	ND
Lacquer Thinner	ND	U	ND	ND	ND	ND	U	ND
Paint Thinner	ND	U	ND	ND	ND	ND	U	ND

(continued)

TABLE 3-3 (continued)

		Surfactant foams						
	Recommendation	Low expansion	High expansion	Protein	Fluoroprotein	Alcohol	AFFF[a]	Mech.
$SiCl_4$	R	C+	C+	C+	C+	ND	F-	ND
i-amyl Alcohol	ND	U	U	U	ND	ND	ND	ND
Ethyl Acetate	ND	U	-	-	U	ND	ND	ND
Butyl Acetate	ND	U	-	-	U	ND	ND	ND
i-propyl Acetane	ND	U	-	-	U	ND	ND	ND
Methyl Acrylate	R	B+	A+	ND	U	ND	ND	ND
Methyl Methacrylate	R	B+	A+	ND	U	ND	ND	ND
SO_3	R	C+	C+	C+	C+	ND	F-	ND
Acetic Acid	R	A+	B+	ND	ND	ND	ND	U
Caproic Acid	ND	U	ND	ND	ND	ND	ND	U
Methyl Bromide	ND	U	U	ND	ND	ND	ND	ND
Butyl Bromide	R	A+	U	ND	ND	ND	ND	ND
N,N'-dimethyl Formamide	ND	U	E-	ND	ND	ND	ND	ND
Tetrachloroethane	R	B+	A+	ND	ND	ND	ND	ND
n-Octanol	R	B+	A+	B+	+	-	ND	U
Tetrahydronaphthalene	R	B+	A+	E-	ND	ND	U	ND
LNG	R	E-	A+	F-	F-	F-	F-	ND
Chlorine	R	B+	A+	B-	B-	ND	E-	ND
Ammonia	R	A+	A+	B+	B+	ND	E-	ND

(continued)

TABLE 3-3 (continued)

Identification of Symbols

[a]AFFF = Aqueous film forming foam

+ = Data available indicating vapor pollution control

- = Data available indicating no vapor pollution control

U = Limited data available - capability uncertain

R = Foam use recommended over spill

ND = Insufficient data

A = Best foam formulation

B = Next best foam formulation

C = Acceptable in some situations

E = Unsuitable foam formulation

F = Deleterious foam formulation

Source: Gross and Hiltz, 1982 (Reference 5).

5. For liquids which are extremely water reactive, high expansion foam provides the best control. This is due to the heats of reaction or solution. The higher the expansion, the slower is the rate of water addition to the reactive liquid.

6. Foams do not effectively mitigate the vapors for liquefied gases which are heavier than air and not water reactive. The water draining into the liquefied gas exaggerates the boil off rate. The released vapors, being nonbuoyant, are not readily dispersed. There are reports of foam being effective against butane, but the data from the tests of this program are not in agreement.

7. For liquefied gases such as ethylene which are buoyant at ambient temperatures, a high expansion foam blanket acts as a heat source. The vapors rising through the foam increase in temperature and dispersion of the released vapor is enhanced.

8. Laboratory tests can be conducted to predict the behavior of foams under field conditions.

9. Environmental conditions such as wind and rain are more detrimental to high expansion foams than to low expansion foams.

10. High expansion foams appear to mitigate a spill by containing the vapors within the foam mass so a vapor-liquid equilibrium can be maintained, thus reducing the driving force towards vaporization.

11. Low expansion foams appear to mitigate the vapor by forming a barrier to prevent vaporization.

12. Foams are an inexpensive, effective method of initial vapor control during an accidental spill, provided the correct foam made from a quality agent is used.

13. The foam agent which produced the best results in terms of vapor mitigation was the metal stearate-based alcohol type foam. This foam agent was better than the newer forms of polar solvent foams. The alcohol type foams were more difficult to apply, more was needed to establish a desired thickness, and the foam cover is fairly stiff. However, once the foam cover was established, it provided good mitigation of vapors.

No data are available which quantifies the achievable reduction efficiency.

Control by chemical means were studied by Brown et al.[6] Water dilution and chemical neutralization were considered to be relatively effective, however often produced unwanted hazardous side effects.[6] Data which quantify emission reduction effectiveness for these techniques are limited. The effectiveness of a similar technique, application of surfactant on a surface impoundment, was estimated by MITRE at 25 to 75 percent.[2] It is expected that the control efficiency of these methods would fall within the same range.

Control of spills by adsorption or cooling was considered by Brown et al. to be only slightly to moderately effective.[6] According to Brown, however, Battelle considers control by cryogenic media to be an area of potential development.[6] Data which quantify emission reduction effectiveness by these methods are also limited. Based upon the available information, these control technologies are not expected to be as effective as either control by mechanical or by chemical means.

Costs

The costs associated with various spillage control technologies are, in general, expected to be relatively low. These costs will range widely, however, as the complexity of the various systems is quite different from case to case. Like emission reduction effectiveness data, cost data for these systems are severely limited. The various costs are expected to be highly dependent upon materials and labor, while operating and installation costs are expected to be relatively low.

The costs of a synthetic membrane cover or foam cover system depend upon the cover material chosen, and the installation method used. The synthetic membrane or foam materials used are not unlike those in use for other similar systems at TSDF processes. Costs for such materials are presented in Section 6 on landfill emission control. They have been estimated to range between $3 and $26/per square yard for synthetic membranes, and $2.25/per square yard for temporary foams.[2] Brown et al. estimated that a spill containment foam system which could deliver approximately 15,000 gal/min of aqueous-based foam would cost approximately $1,300 to implement at a facility.[6]

The costs associated with implementing a water dilution or chemical neutralization system are largely dependent upon the equipment costs involved. The actual cost of chemical agents or water is assumed to be very low in comparison. Brown et al. estimated that a water spray pump machine which can be used to apply a water mist blanket over a chemical spill would cost less than $925 (March 1985 dollars).[6] The costs associated with storing neutralization agents or water to be used for this purpose have not been evaluated.

The costs associated with using absorbents or coolants for spill mitigation are similar to those for water dilution or chemical neutralization. For solid absorbents, the costs would be based upon materials costs only.

CONTAINER MODIFICATION

Introduction

Reduction of spillage and leaks from containers and, consequently, significant reduction of emissions, may be effected by securing the containers themselves. The containers are subject to a variety of stresses, both from within and from outside, including corrosion, denting, and puncture. Encapsulation systems are designed to insulate the containers from the outside and also to contain corrosive materials inside should they leak from the containers. There are two basic types of encapsulation systems, as follows:

- Overpack designs; and
- Directly-applied systems.

Encapsulation systems have only recently found application in industry. This section will present alternatives based on information found chiefly through laboratory test programs.

Description

The basic function of an encapsulation system is to completely enclose an individual container. Emission of vapors resulting from both leakage and breathing loss would essentially be eliminated. Drums placed in an encapsulate would be insulated from mechanical and chemical stresses, and thermal fluctuations. Most encapsulates employ polymeric resins (e.g., polyethylene).[9] Polymeric materials offer several advantages over steel or other materials, including chemical compatibility, corrosion resistance, weight, mechanical resilience, flexibility, strength, and low materials and fabrication cost. Use of polymeric materials allows for fabrication to be done onsite, and also allows the use of readily transportable equipment, thus facilitating their use at a TSDF. In selecting the container modification system most applicable to a specific TSDF, the following considerations must be made in determining the applicability of the system:

- Type of material being handled. Chemical compatibility, density, and volatility are all factors which must be considered.
- Type of containers being handled. Containers of a certain size or material of construction may not be well handled by a certain modification.
- Containerized waste fate. Encapsulation is most suited to unit disposal.[9] Whether the containers are to be disposed of, shredded, or reused.
- Manpower requirements. Whether or not a facility will have the manpower required for a certain container modification procedure.
- Availability of materials. Encapsulation requires the use of certain special materials.

Overpack Systems--

An overpack is essentially a jar into which a container is placed. The overpack is then covered and sealed, permanently. By sealing the container into the impermeable overpack, emissions from waste are eliminated. Overpacks are available commercially, and can be produced by any manufacturer of rotomolded plastics.[9] They can be made in a variety of sizes, capable of handling any size from small containers to 55-gallon drums. Overpacks are commonly packed with sorbent material which fills the gap between the drum and the overpack wall.[10] The sorbent material will act to stabilize the drum within the capsule, insulate the drum from both thermal fluctuations and physical shocks, and absorb leaking waste. The key difference between available overpack systems is in the method by which they are sealed.[9,10] The two designs described in the literature are as follows:

- Single layer, friction welded;[10] and
- Double layer, fiberglass-lined.[9]

Overpacks are the more applicable of the two types of encapsulation systems. They are especially well suited to handling highly reactive or corrosive wastes.

Single Layer, Friction Welded--Single layer type overpack systems are generally formed from polyethylene, although polypropylene and polyvinyl chloride types have been tested. The systems come in two pieces: the capsule and the cover. To seal the capsule, friction welding has been proposed as the most effective means of closure. (Other designs use mechanical closure or adhesives.) A typical overpack welding system is shown in Figures 3-1 and 3-2. The system employs a welding device which may be made transportable for use at a TSDF. The primary design considerations in implementing this type of system are overpack materials (availability and compatibility), manpower requirements, and type of containers being handled.

Double Layer, Fiberglass Lined--Double layer overpack systems also use polyethylene, or polypropylene on the outside layer, and thus function identically to single layer designs. The difference is that double layer systems employ a fiberglass inner layer which is formed directly onto the container, thus giving a seamless seal. The outer layer then adheres to the fiberglass layer, eliminating the need to seal the cover. Double layer systems require two applicator systems: a spray gun applicator for the fiberglass inner layer, and a fusion mold system, as shown in Figure 3-3, for the polyethylene layer. The primary design features to be considered in selecting a double layer system are the availability of materials, the manpower requirements, the application procedure, whether or not to use sorbents, and the transportability of equipment.

Directly-applied Systems--

Directly-applied systems involve spraying or brushing resin or other material onto the surface of the container. Such systems have the advantage

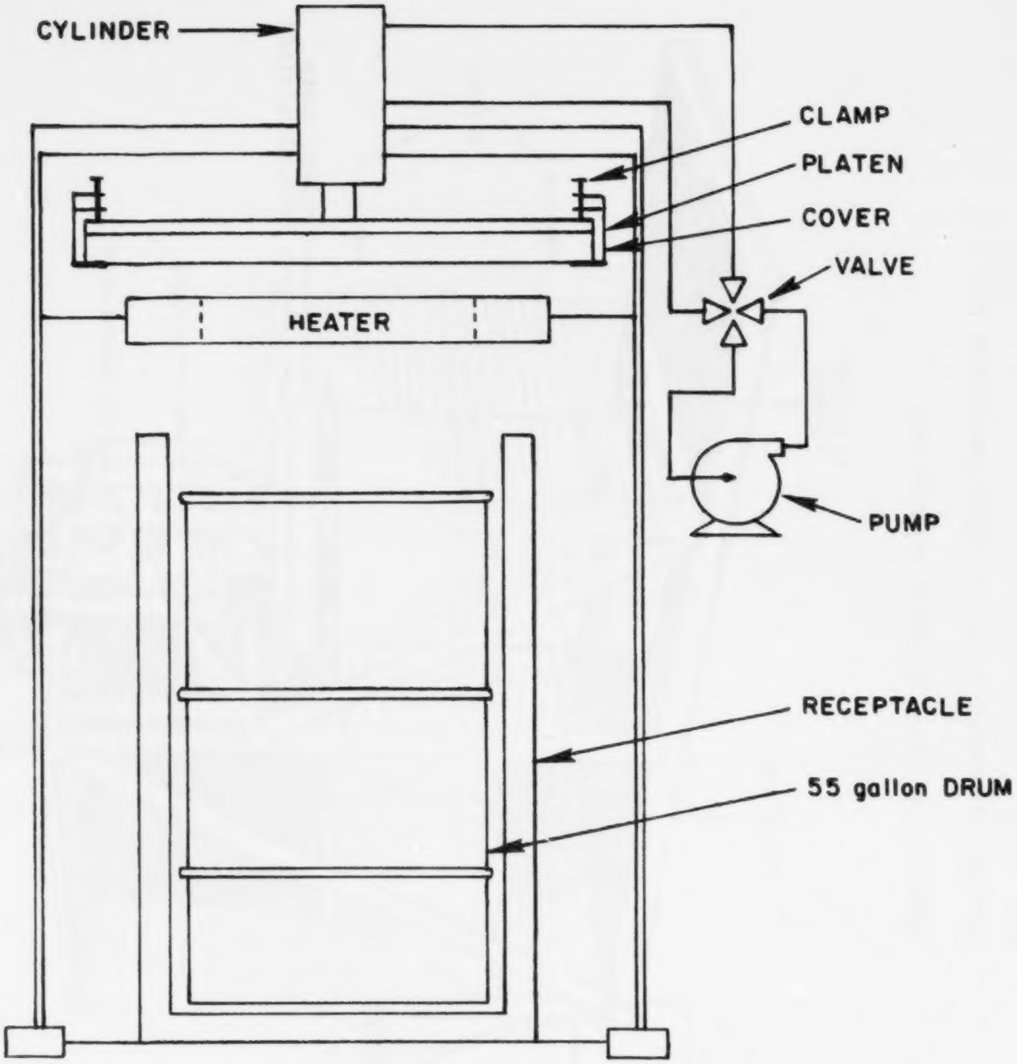
CYLINDER
CLAMP
PLATEN
COVER
VALVE
HEATER
PUMP
RECEPTACLE
55 gallon DRUM

Figure 3-1. Apparatus for encapsulating 208-liter (55-gal) drums holding hazardous wastes.

Source: Lubowitz & Telles, 1981 (Reference 10).

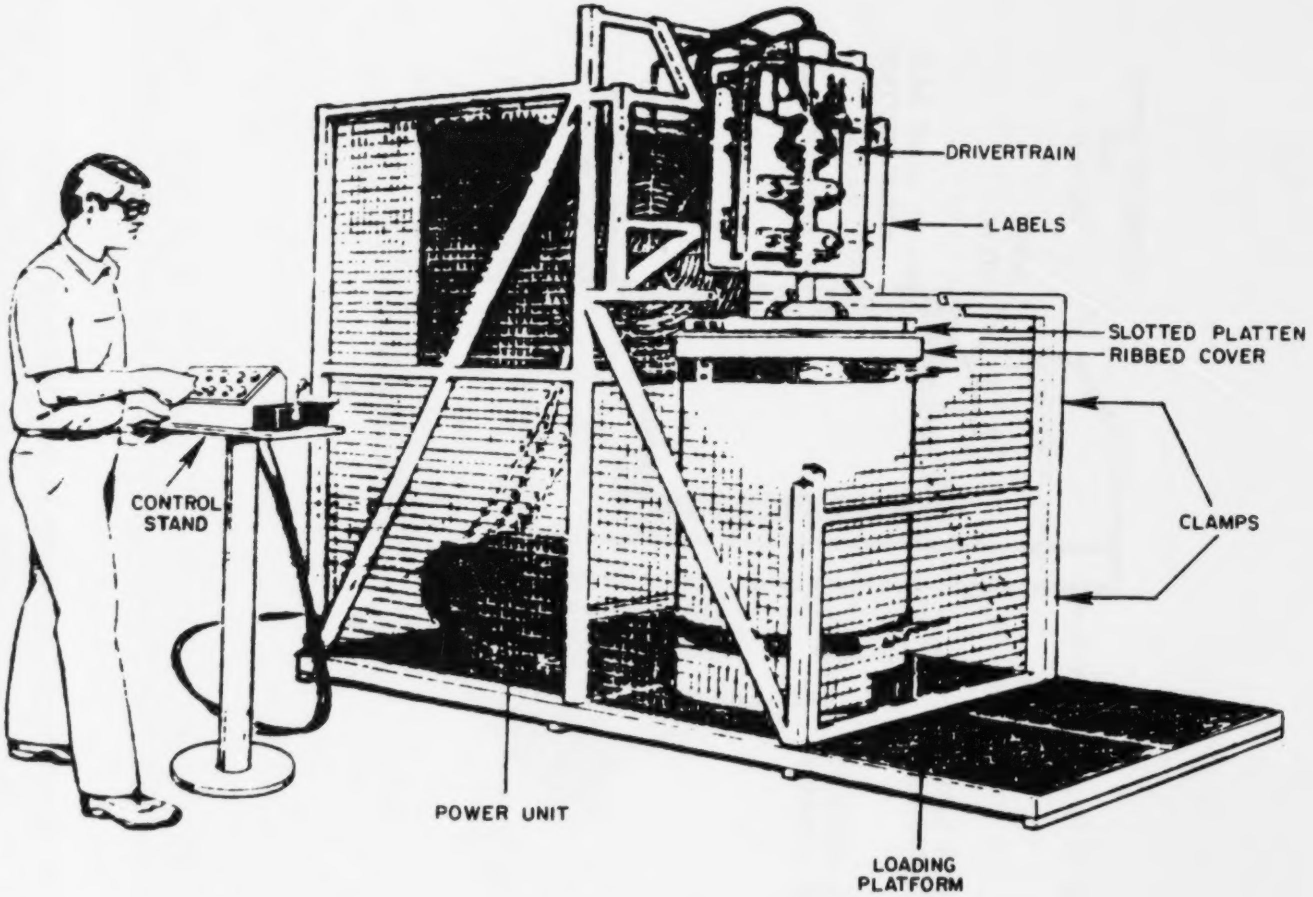
DRIVERTRAIN
LABELS
SLOTTED PLATTEN
RIBBED COVER
CLAMPS
CONTROL STAND
POWER UNIT
LOADING PLATFORM

Figure 3-2. EPP overpack welding unit.

Source: Lubowitz & Telles, 1981 (Reference 10).

Reproduced from best available copy.

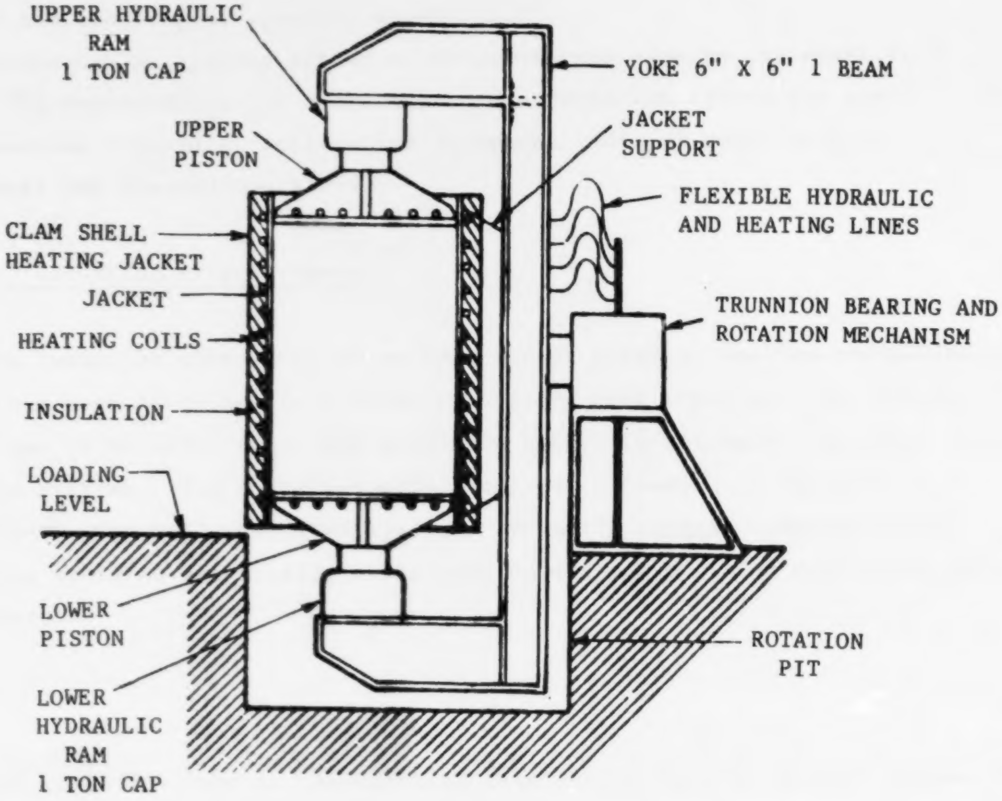
UPPER HYDRAULIC RAM 1 TON CAP
YOKE 6" X 6" 1 BEAM
UPPER PISTON
JACKET SUPPORT
FLEXIBLE HYDRAULIC AND HEATING LINES
CLAM SHELL HEATING JACKET
JACKET
TRUNNION BEARING AND ROTATION MECHANISM
HEATING COILS
INSULATION
LOADING LEVEL
LOWER PISTON
ROTATION PIT
LOWER HYDRAULIC RAM 1 TON CAP

Figure 3-3. Side view of the polyethylene fusion mold.

Source: Lubowitz & Telles, 1981. Reference 9.

of being applicable to any size or shape container, however do not insulate the container as well as an overpack system. Such systems also have no seams. A variety of materials are used in this application, including fiberglass, polyethylene, and concrete. The primary considerations in implementing a directly-applied encapsulation system are container materials, chemical compatibility, manpower requirements, application procedure, and the storage and handling of spray-on materials.

Encapsulation systems appear to be relatively easy to implement at a TSDF. The requirements for operating an encapsulation system are the encapsulation materials, application equipment (both of which must be purchased) and trained operators.

Emission Reduction Effectiveness

The reduction efficiency of an overpack or directly-applied encapsulation system has been described in several laboratory test reports. The systems were found to be water-tight and performed better in strength tests than steel overpack systems. The reduction efficiency was estimated to approach 100 percent with well insulated systems. Volatile organic compound (VOC) emissions would be essentially eliminated unless extreme heat conditions were encountered.

Costs

The costs involved in implementing this system include capital equipment, material, and labor. The equipment includes conventional drum-handling equipment, spray guns, or overpacking apparatus. Materials costs include costs of resin and sorbent material. A total cost estimate of $65 to $90/drum for overpack systems, and $26 to $40/drum for directly-applied systems has been calculated based upon encapsulation of a 55-gallon steel drum as described in this section.

OPERATING PRACTICES

Introduction

Because container leakage and spillage play such a significant role in emissions from containerized waste, operating practices are a potentially significant area in which to effect emission reductions. Changes in operating practices would be specifically intended to reduce mishandling or degradation of the containers. This subsection will focus upon three changes in operating practices, as follows:

- Improved drum equipment and/or procedures;
- Leak detection and repair programs; and
- Submerged loading.

Changes in operating practices are applicable to any TSDF.

Description

The purpose of improving operating practices is to insure that mishandling of containers is prevented, factors which lead to the degradation of containers (such as storage in a damp area) are reduced or eliminated, and conditions which exacerbate the volatility of a waste are reduced. In implementing changes in operating practices at a TSDF, the following considerations must be taken into account:

- Manpower requirements. Whether or not a facility has the personnel required to implement a certain change in operating practice.
- Storage procedures. The way containers are stored may determine the applicability of a certain change in operating practice.
- Input/output. The turnover rate a facility maintains may determine the applicability of a certain change in operating procedure.

The three changes to be reviewed in this subsection are quite common practices at TSDFs and, as such, adhere to the above criteria.

Improved Drum Handling--

By making improvements in the procedures used in the handling of containers, either by purchase of better equipment or use of new procedures, mishandling of drums can be reduced. Mishandling of drums is the primary cause of spills and damage to containers (leading to leaks) at TSDFs.[1] The most common procedure now employed is to move drums, either two or four at a time, by forklift. Spills or damage commonly occur when drums fall off of the pallets when they are in transit, or when the forklift collides with another object. Handling spills also occur during unloading of drums, and during drum disposal operations. Three changes which are common are as follows:

- Drum "grabber" equipment;
- Slow pouring; and
- Drum decontamination.

Drum "Grabber" Equipment--Drum grabbers are specially made forklifts designed for transport of 55-gallon drums. Drum grabbers are equipped with a device which wraps around the drum, thus providing a secure hold. In some designs, the drums are further protected by bumpers or screens so that damages in the event of a collision can be reduced or eliminated.[2] The primary considerations involved in selecting drum grabber equipment are available space requirements in the storage area, size of drums handled, and drum turnover rate.

Slow pouring--Pouring of waste material from drums often is a major source of spills. Through more careful procedures, these spills can be reduced. Slow pouring may be accomplished either by implementing equipment such as spouts, or simply by improved technique. The considerations to be made in implementing this procedure are present pouring method (manual or mechanical), waste viscosity, and drum type.

Drum Decontamination--After waste material has been poured from the drums, they are either reused or disposed of. Residual waste often spills during handling of empty drums. These spills can be eliminated by decontamination procedures. Decontamination involves scrubbing of the drum walls, either manually, mechanically, or chemically. A variety of cleaning solvents may be used for this application. Among the primary considerations involved in this procedure are type of drums handled, cleaning solvents, control of volatile emissions from cleaning materials and operations, and disposal of waste materials.

Leak Detection and Repair (LDAR) Programs--

By instituting a program for continuously checking containers and immediately repairing them if potential for leaking exists, a facility can reduce the number of leaks that occur, increase the speed of response to those that do occur and thus reduce emissions. Various monitoring techniques that can be used in a leak detection program include individual component surveys, unit area ("walkthrough") surveys, and fixed point monitoring systems.

Individual Component Survey--An individual component survey involves checking each potential container leakage source for VOC leaks. This may be accomplished by spraying a suspected leakage source with a soap solution and observing bubble formation or measuring VOC concentration with a portable VOC detector. In selecting an individual component survey LDAR program, the primary considerations are the number of containers, manpower requirements, personnel access to the containers and waste products.

Walk-through Survey--A walk-through survey involves checking each container for VOC leaks by measuring the VOC concentration close by. This is accomplished with a portable VOC measurement device. This type of survey has the advantage of being quicker and requiring less manpower, but is not as thorough as an individual component survey. The primary considerations involved in selecting a walk-through survey for LDAR are the number of containers, prevailing weather (especially wind) conditions, access to containers, and manpower requirements.

Fixed-Point Surveys--A fixed-point survey involves placing a continuous monitor in various locations at the storage area. LDAR programs would then involve responding to an audio alarm system or monitoring the measurements on a periodic basis. These programs can result in leaks being detected sooner. Like walk-through surveys, however, they are not as thorough as individual component surveys and, in addition, have higher equipment costs. The primary considerations involved in selecting this option are the number of containers, size of storage area, manpower requirements, weather conditions, and number of units required. Of the three options, fixed-point surveys have found the most widespread application to detection of hazardous or toxic emissions.[13]

Submerged Loading--

Loading of containers is often done at a TSDF. Emissions from loading of containers, like storage tanks, can be reduced by employing submerged filling. For open containers, submerged filling would require a nozzle which would be placed at the bottom of the drum. For enclosed containers, this may require a pressure attachment to the bung hole. The primary considerations involved in instituting submerged loading procedures are the type of drums being filled, and the type of waste material.

Other Practices--

In addition to those described in detail above, there exist many other changes that may be made in operating practices at a TSDF which may contribute to reduction of emissions. These may include prohibiting drum stacking, segregating wastes, and not allowing containerized wastes to be stored, handled, or disposed of at all.

Implementation of the changes in operating practices at a TSDF are dependent upon several factors, including new equipment, manpower, and overall system complexity. Most of the changes described above are considered to be extremely easy to implement.

Emission Reduction Effectiveness

Changes made in operating practices at a facility which handles containerized hazardous wastes are expected to result in the reduction of air emissions due to decreased mishandling, spills, and leaks. No detailed information has been published, however, which indicates the effectiveness of such measures relative to add-on control systems. Based upon engineering judgment, these measures are considered moderately effective, but not as effective as many of the add-on control systems.

The effectiveness for better drum handling equipment is a direct function of the reduction in accidents and mishandling of drums at a facility. A survey of manufacturers of drum handling equipment revealed that such equipment has been found to be responsible for reducing mishandling incidents by 50 to 75 percent.[12]

The effectiveness of leak detection and repair programs may be measured in terms of the percentage of previously undetected leaks which are detected in the surveys. OAQPS reports that the effectiveness of various LDAR programs is as follows:[13]

- Individual component survey: 99 percent
- Walk-through survey: 50 percent
- Fixed-point survey: 33 percent.

The effectiveness of submerged loading has been studied extensively for the filling and emptying of storage vessels. AP-42 reports that submerged loading can result in emissions reductions of 66 percent.[15]

Costs

The costs involved in implementing operating practice changes at a TSDF are expected to be relatively low, based upon limited information. These costs are dependent upon the materials and/or equipment requirements, and labor. Operating costs are generally expected to be low.

Improving drum handling equipment may involve costs associated with purchasing drum grabber equipment or decontamination equipment and materials. Decontamination procedures would also involve added materials handling and disposition costs. Slow pouring would not involve any additional costs, except those that may be incurred due to decreased rate of operation or added manpower required. Drum grabber equipment was found to cost in the $300 to

$600 range, based upon conversations with suppliers.[12] Costs of decontamination systems could not be determined based upon the available information.

The costs involved in leak detection and repair programs essentially involve just equipment and labor costs. Based on conversations with suppliers, VOC monitoring equipment costs are estimated to be within the $200 to $1,000 range for portable units, and $500 to $3,000 for fixed monitors.[14] Labor costs would vary with the size of the facility.

The costs of submerged loading essentially involve just equipment costs. No information detailing the cost of longer fill pipes, pressure nozzles, etc. was found. It is estimated that such costs would be quite low.

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SECTION 4

CONTROL OF EMISSIONS FROM STORAGE TANKS

INTRODUCTION

There are two basic types of tanks found at TSDFs: open-top and closed-top. The tanks in use range in capacity from 5000 to 1,500,000 gallons. Most are above ground, although some liquid wastes are stored in submerged tanks. Hazardous materials are generally brought to a facility by tank truck or rail car, and the tanks are loaded, generally via pipeline, by either splash or submerged filling techniques.

Hazardous constituent releases from storage tanks can occur via two mechanisms for closed-top tanks: working loss and breathing loss. Working loss, which accounts for a more significant percentage of emissions, occurs when liquid being put into a tank causes the displacement of an equal volume of vapor. Breathing loss occurs when a volatile compound is vaporized and released from tank due to temperature fluctuations affecting the tank. For open-tanks, air releases of waste constituents are a function the diffusion and mass transfer from the bulk material.

The control options available to a facility which stores volatile waste material in tanks can be classified as follows:

- Roofs and associated control systems;
- Covers;
- Insulation; and
- Vapor control systems.

Table 4-1 provides an overview of advantages and disadvantages of control alternatives described in this section. This section will describe technology

TABLE 4-1. ADVANTAGES AND DISADVANTAGES OF STORAGE TANK EMISSION CONTROL ALTERNATIVES

Advantages	Disadvantages
ROOFS AND ASSOCIATED CONTROLS	
Fixed Roofs:	
• Highly effective in reducing emissions from open tanks or external floating roof tanks.	• Very high initial costs.
• Provide a permanent rigid cover.	• Very heavy--may not be applicable to existing tanks due to structural considerations.
• Insulates constituents from solar irradiation, rain, and wind.	• Requires venting due to internal pressure considerations.
• Very durable.	• May necessitate changing tank loading procedure.
• Very low maintenance costs required.	
• Easy to retrofit onto existing tanks (in terms of design).	
Floating Roofs (External and Internal):	
• Very highly effective in reducing emissions from tanks (higher than fixed roofs).	• Very expensive--particularly in terms of maintenance (relative to fixed roofs).
• Provides a permanent, rigid cover.	• Heavy--may be limited by structural considerations.
• Insulates constituents from solar irradiation and wind and rain.	• Requires that inside design of tank contain no support columns, or beams along side.

(continued)

TABLE 4-1 (continued)

Advantages	Disadvantages
Floating Roofs (External and Internal) (Cont'd):	
• Very durable. • Easy to retrofit to existing tanks. • Need not be vented. • Not as heavy as fixed roofs. • Less expensive initially than fixed roof.	• Difficult to maintain. • May warp or sink. • Not as good insulator from external forces (particularly heat) as fixed roofs. • May require alteration of loading procedures.
Seals:	
• Increase effectiveness of all floating roofs. • Simplistic designs, easily adaptable to existing systems. • Relatively inexpensive to install and maintain. • Durable. • Provide good thermal insulation, vapor permeability. • Relatively low costs, overall.	• Application limited by design of primary seal system, internal design of tank. • May increase weight of roof. • May not be applicable for use with all waste substances (e.g., viscous materials). • Weather conditions hinder effectiveness.

(continued)

TABLE 4-1 (continued)

Advantages	Disadvantages
Vents:	
● Necessary to reduce internal pressure buildup inside enclosed tanks. ● Simple designs--easy to install on existing vessels. ● Inexpensive to implement--only initial costs are involved. ● Durable. ● Easy to maintain.	● Increases working losses--not well suited for highly volatile substances. ● By itself, not a control. Requires the use of vapor control system.
COVERS	
● Highly effective in reducing emissions. ● Simple designs, easily adaptable to more than one storage tank at a facility. ● Easy to implement. ● Applicable to varying size and shape storage tanks. ● Provides a close-fitting cover, more flexible than a roof.	● Less effective in reduction of emissions than roofs. ● More permeable by vapors and gas. ● Less durable than roofs. ● Low strength characteristics. ● Poor weather resistance. ● Requires maintenance.

(continued)

TABLE 4-1 (continued)

Advantages	Disadvantages
● Light weight--will not sink. ● Will not warp or corrode. ● Adaptable to changes in constituent type. ● Less costly than roofs, overall. ● Generally low operating costs. ● Removable.	● Will transmit heat directly to liquid. ● High maintenance and installed costs.
INSULATION	
● Reduces solar irradiation and wind on tanks and tank constituents. ● Simplistic designs. ● Widespread usage in industry. ● Many available options to choose from. ● Highly adaptable to any storage tank. ● Can be used in conjunction with other control technology. ● Requires little or no space.	● Poor weather resistance. ● Applied directly to tank--effect may be limited by design constraints. ● High maintenance costs. ● Emission reductions achievable are low.

(continued)

TABLE 4-1 (continued)

Advantages	Disadvantages
INSULATION (Cont'd)	
● Uses inexpensive materials. ● Low installed costs. ● Particularly attractive for open or external floating roof tanks.	
VAPOR CONTROL SYSTEMS	
● Capable of achieving the highest emission reduction efficiencies of the control options described. ● Completely remove vapor from tanks. ● Equally effective in reducing working and breathing losses. ● Best available technology for highly volatile and/or toxic substances. ● Very safe to operate. ● Basic design of systems are simple--they are easy to operate; and easy to design to fit a tank.	● Most costly of all control options discussed for storage tanks. ● Highly complex systems to maintain. ● Manpower required. ● Materials required. ● Space required. ● Accessibility required. ● Requires enclosed tank. ● Requires equipment for the disposition of vapor control process products.

(continued)

TABLE 4-1 (continued)

Advantages	Disadvantages
VAPOR CONTROL SYSTEMS (Cont'd)	
• Can be applied to one or more than one tank vent systems at once. • Can be a single-pass or multiple-pass system. • Can selectively recover constituents. • Adaptable to a variety of wastes--can use even if wastes stored changes. • Can regenerate carbon beds for continuous use. • Have found widespread usage at TSDFs.	• Subject to fire and explosion hazards. • Can be subject to design capacity limitations. • Performance is affected by prevailing weather conditions.

options provided in Table 4-1 under each of these classifications. Example systems will be cited, and the relative emission reduction effectiveness and cost of implementing these options to existing TSDFs will be examined.

ROOFS

Introduction

Storage tank roofs serve two basic purposes: (1) to keep tank constituents contained; and (2) to shelter the constituents from external forces such as solar irradiation, wind, and precipitation. Three basic roof designs for storage tanks, include:

- Fixed roof;
- External floating roof; and
- Internal floating roof.

All three types have found widespread application at TSDFs.[1]

Description

A storage tank roof is defined as any rigid, permanently affixed mechanism for enclosing tank constituents from the environment. A roof is primarily intended to keep tank constituents contained, while excluding environmental factors from contact with these constituents. As a control option, roofs are particularly attractive as they serve to limit working losses. A variety of designs are available, including fixed roofs, roofs that move as the liquid level of a tank changes, and roofs with and without vapor seals and pressure vents. In addition, roofs may be made from a variety of materials. In determining which design is most applicable to a particular storage tank at a TSDF, the following factors should be considered.

- Tank Design. The size, shape, structural reinforcement, and structural strength of a storage tank.
- Type of material being stored. The volatility, viscosity, and chemical nature of the materials being stored.
- Tank loading procedure. How the tank is loaded, when, and how often the tank is loaded and emptied.
- Weather conditions. Sun, wind, and rain patterns of the local area.

The three basic roof designs have all found widespread usage at TSDFs. A description of each roof design, how they may satisfy the above criteria for a particular storage tank, and the considerations involved in formulating a specific design is provided below.

Fixed Roof--

A fixed roof is defined as any rigid cover which is permanently affixed to the top of a storage tank. A variety of fixed roof tanks are shown in Reference 4. A fixed roof is the most common of the three roof designs. There are three styles of fixed roofs: conical, domed, and flat. Conical roofs are the most common of the three.[2]

Fixed roofs may be constructed of steel, aluminum, or plastic. Choice of materials is largely dependent upon the tank design. Fixed roofs may also be equipped with various appurtenances, such as vents, sampling ports, and manholes. Fixed roofs may be coated on the inside, insulated, multilayered, or painted a different color in an effort to reduce the effects of solar irradiation of tank contents. The following considerations which are involved in formulating a design for a fixed roof.

- Roof size and weight. Since storage tanks are constructed with thin walls, the weight of a fixed roof may be limited by the structural constraints of the tank.
- Roof reinforcement. The fixed roof may require columns, or bracings in order to be applicable to a tank.

- Roof venting. Due to the volatility of tank constituents, it may be necessary to incorporate vents into the roof design to reduce internal pressure buildup.
- Inflow/outflow pipe installation. Installation of a fixed roof requires eliminating top loading procedures and installing inflow/outflow pipes.

Fixed roofs are considered to be relatively effective in reducing emissions from tanks, while remaining simple so that costs are not a major factor. Analyses of reduction effectiveness and cost are presented later in this section.

Pressure Tanks--A pressure tank is a special type of fixed roof tank design. They are specifically designed to withstand relatively large internal pressures. These types of tanks are the most commonly used for storage of highly volatile and/or toxic materials.[3] They are constructed in various sizes and shapes, depending on the operating pressure range. Noded spheroid and hemispheroid shapes are generally used for low pressure (117 to 207 kPa), while horizontal cylinder and spheroid designs are generally used for high-pressure tanks (up to 1827 kPa).[4] Pressure tanks generally operate with no emissions, as they are an enclosed system.[3] Because of their complex design and use of structural materials, such tanks tend to be much more expensive. The primary considerations involved in selecting a pressure tank design include the operating pressure range, loading and unloading procedure, and tank maintenance considerations.

Flexible Diaphragm Tanks--Another specially modified type of fixed roof tank incorporates a synthetic membrane, stretched over the top of the vapor space. The membrane (also called "diaphragm" or "bladder") serves to limit the emission of vapor due to working losses by expanding within the fixed roof as the tank is filled. By expanding, the volume of vapor which is displaced when the tanks is filled with liquid is not immediately pushed out of the tank. The diaphragms are generally made from a synthetic rubber material or polyvinyl chloride. The primary considerations involved in implementing a flexible diaphragm system are the tank design (structural limitations), compatibility of the diaphragm with the tank constituents, and diaphragm venting.

External Floating Roof Tanks--

A floating roof is defined as any rigid cover permanently incorporated into the storage tank design which moves such that the volume of the tank varies as the tank is filled and emptied. A floating roof operates by resting directly upon the surface of the liquid. Storage tank working losses are reduced because the floating roof imparts a slight pressure upon the liquid, thus eliminating available vapor space. An external floating roof tank utilizes such a roof as the sole means of enclosure. Floating roofs are always equipped with a flexible vapor seal at the perimeter.[3] In general, they are constructed of aluminum or steel, although the use of plastic materials has become increasingly common. There are several different types of roof designs in use at TSDF storage tanks, the most common of which are:

- Pan roofs;
- Pontoon roofs; and
- Double-deck roofs.

Pan Roofs--Pan roofs have found widespread usage for approximately 50 years.[5] A pan roof is the simplest floating roof design, involving a simple flat cover resting directly upon the liquid surface as shown in Figure 4-1. Emissions are controlled by such a design because the exposed surface area of the liquid is virtually eliminated, and the weight of the roof imparts a slight pressure which decreases volatility. Pan roofs almost always are equipped with flexible perimeter seal system. There are basically two types of pan roofs in use, including: (1) aluminum sandwich panel roofs with a honeycomb aluminum core, and (2) flat steel pans. Pan roofs have found widespread usage because of their simplicity and emission reduction effectiveness.

There are several disadvantages associated with pan roofs, however, including: (1) they require considerable support or trussing to prevent them from buckling; (2) they are subject to warping or holes which can lead to sinkage; (3) there are no effective drainage systems to release liquid condensing on the top of the roof; and (4) in direct sunlight, heat is very

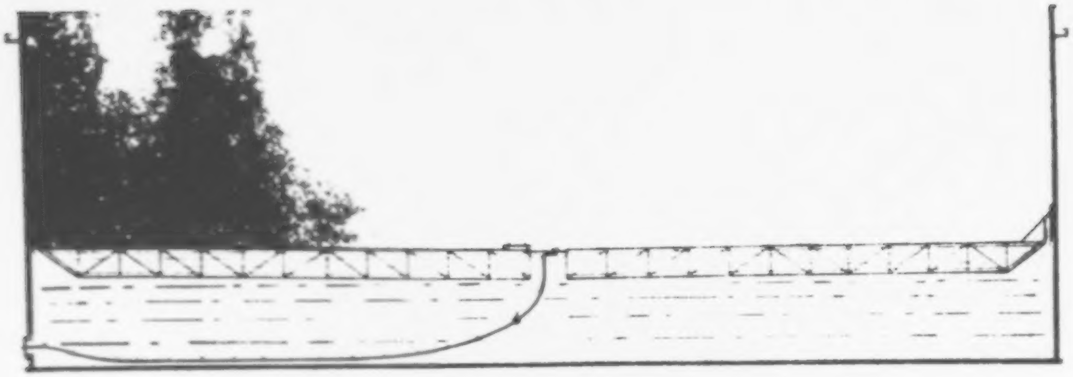


Figure 4-1. Pan-Type Floating Roof Tank.
Source: API, 1973 (Reference 4).

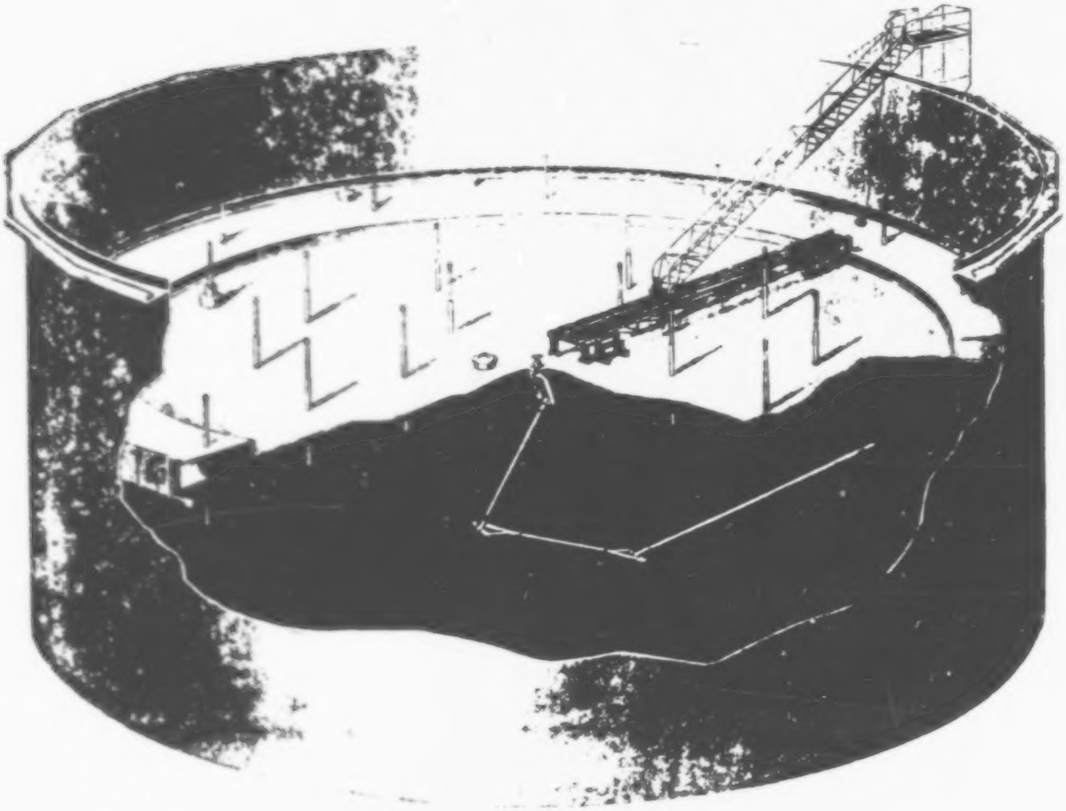


Figure 4-2. Pontoon-type Floating Roof Tank.
Source: API, 1973 (Reference 4).

readily transmitted through the metal plate to the tank contents, potentially increasing the substances volatility. The primary design considerations involved in selecting an applicable pan roof are the tank design (diameter and weight capacity), roof thickness, seal system, and support structure. Retrofit of a floating roof to an existing tank is a very common method employed to effect emission control. A major limitation to retrofitting floating roofs is the need for internal reinforcement (columns, bracings) of an existing tank.

Pontoon Roofs--A pontoon roof, as shown in Figure 4-2, is similar to a pan roof, except that it does not rest directly upon the liquid surface but instead upon pontoons. This results in the creation of a vapor space between the roof and the liquid surface, greatly increasing thermal insulation. Like a pan roof, a pontoon roof will control working losses by limiting the available vapor space and by imparting a slight pressure on the liquid. Pontoon roofs are always equipped with a flexible perimeter seal.[5]

Design variations for pontoon roofs include the following considerations.

- Shape of the roof. Flat, convex, and conical roof designs are commonly used.
- Drainage system. Hinged or flexible connections may be used to recycle vapor condensed on the top to the liquid space.
- Pontoon design and location. Pontoons of various size and shape are in use (depending upon roof design), and may be located either at the perimeter (most common) or the center, or both.

Pontoon roofs are considered to be most applicable to larger diameter storage tanks. Design considerations involved in selecting the most appropriate pontoon roof design are the tank design, the pontoon design (including the compatibility of pontoon material with the tank constituents), the roof design, the seal system, and the design of any roof support system needed.

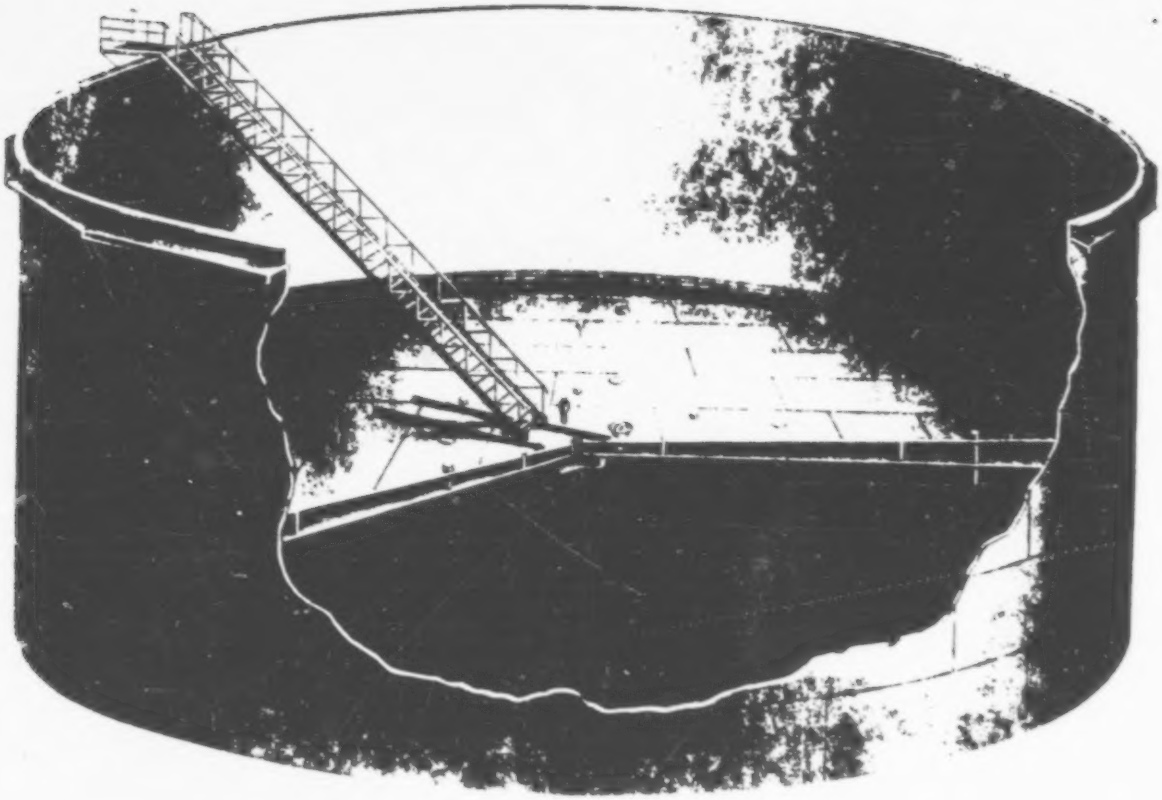
Double-deck Roofs--A double-deck roof is essentially a system which incorporates design elements of both pontoon and pan roofs, as shown in

Figure 4-3. The lower deck, like pan roof, rests directly upon the liquid surface. Between decks is a series of compartments, set up so as to provide a dead air insulator so that heat is not easily transmitted through the roof to the liquid. The upper deck is equipped with drainage and seal systems. This roof design will be buoyant and nonwarping, while providing less available space for volatilization. The disadvantages of such a system are its weight, high cost, and difficulty to retrofit to tanks. The primary considerations involved in selecting a double-deck floating roof system are the tank design, the roof mass, reinforcement or support system, seal system requirements, and drainage system.

Internal Floating Roof Tanks--

A floating roof tank which is covered by a fixed roof is defined as an internal floating roof tank. A tank equipped with this roof type incorporates design elements of both fixed roof and floating roof tanks described earlier. Internal floating roof tanks are the most effective in controlling emissions, as the floating roof greatly reduces working losses, and the fixed roof contains the breathing losses.[2] The types of internal floating roofs used in such tanks are of the same designs as in external floating roof tanks: pan roofs, pontoon roofs, and double-deck roofs. The use of pan roofs in internal floating roof tank, is widespread, as the provision for thermal insulation is best of the three.[4]

The use of internal floating roof tanks is more widespread at TSDFs than external floating roof tanks, but not as widespread as fixed roof tanks. Internal floating roof tanks are particularly applicable to higher volatility, low molecular weight substances. Design considerations involved in selecting an internal floating roof tank design are the tank diameter and structural strength, tank venting requirements, floating roof drainage and seal system, floating roof reinforcement, and maintenance considerations. Retrofit of an internal floating roof to an existing fixed roof tank is generally impossible, but installing a fixed roof on an existing external floating roof tank is the most commonly performed retrofit control change.



Reproduced from best available copy.

Figure 4-3. Double-Deck Floating Roof.
Source: American Petroleum Institute, 1973 (Reference 4).

Seal Systems--

Most, if not all, floating roofs employ a vapor seal system. A floating roof seal is designed to seal the gap between the perimeter of the floating roof and the tank wall, such that vapors will not escape through the gap to the atmosphere.[3] The seal is attached to the roof, and slides against the tank wall when the roof moves up and down (as the tanks is emptied or filled). There are two classifications of seal systems: primary and secondary. A secondary seal provides additional coverage to the primary seal. There are differences between the types of vapor seals used on external and internal floating roof tanks, as described below.

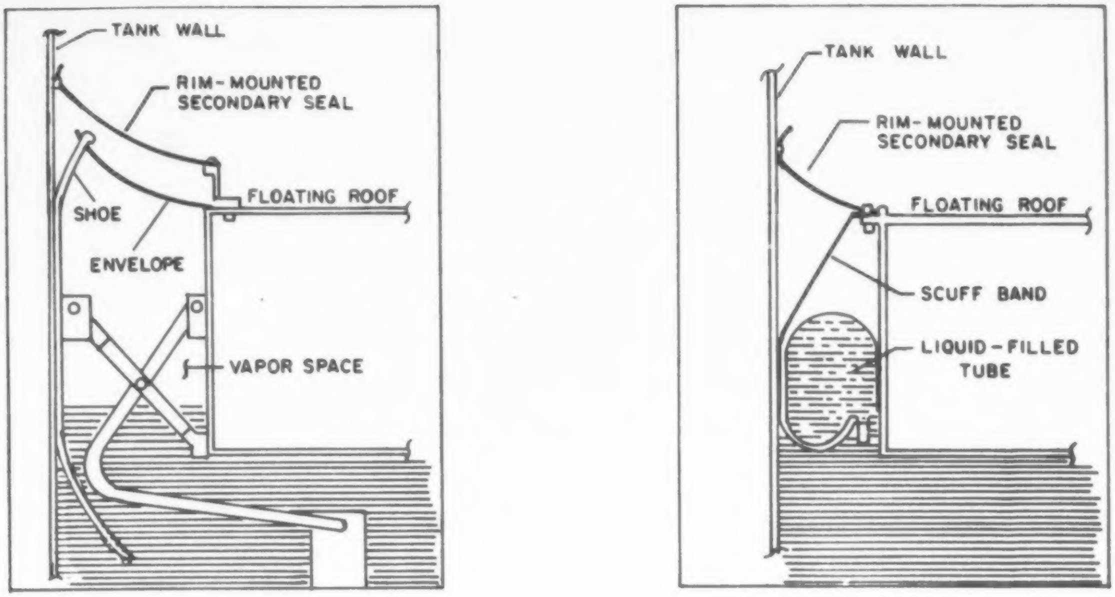
External Floating Roof Tank Seals--

There are basically three types of primary seals used on external floating roof tanks: mechanical shoe seals, liquid filled seals, and resilient foam-filled seals.[2] These three comprise the majority of vapor seal designs in use today.

Mechanical Shoe Seals--[2]A mechanical, or metallic shoe seal is characterized by a metallic sheet (the "shoe") held against the vertical tank wall, as shown in Figure 4-4a. The shoe is connected by braces to the floating roof and is held tightly against the wall by springs or weighted levers.

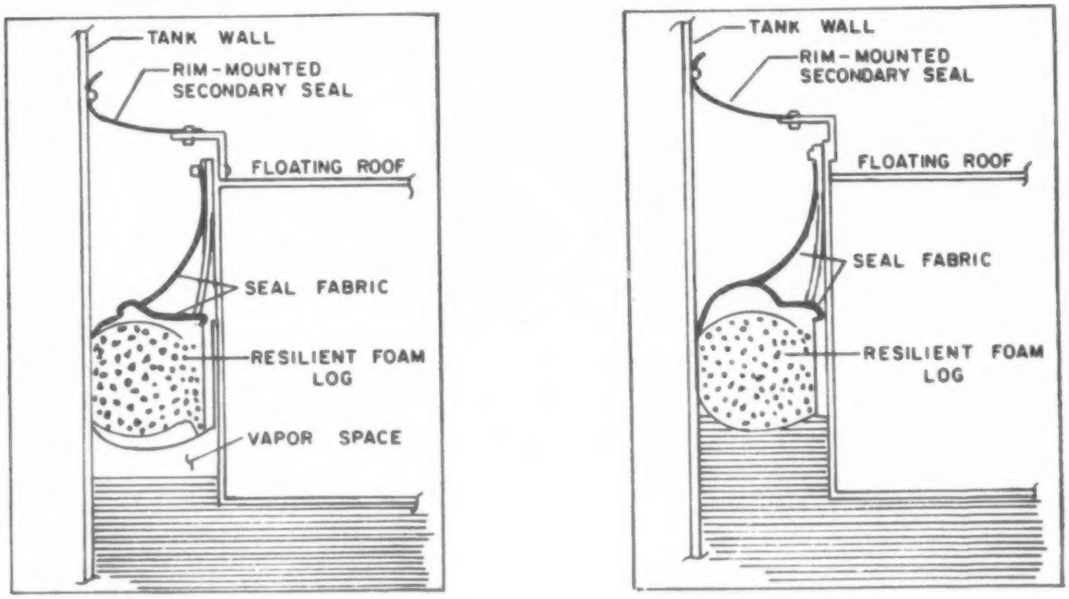
Liquid-filled Seals--[3]A liquid-filled seal consists of an envelope, made either from fabric or flexible polymeric tubing, filled with liquid and sheathed with a resilient fabric scuff band, as shown in Figure 4-4b. The liquid is commonly a petroleum distillate or other liquid which will not contaminate the stored product if the tube ruptures. Liquid seals are mounted such that they rest directly upon the liquid surface, providing no vapor space below the seal.

Resilient Foam-filled Seal--[2]A resilient foam-filled seal, as shown in Figure 4-4c and d, is similar to a liquid-filled seal except a foam log replaces the liquid. Such a system is mounted on or above the liquid surface, as shown.


TANK WALL
RIM-MOUNTED SECONDARY SEAL
SHOE
ENVELOPE
FLOATING ROOF
VAPOR SPACE
TANK WALL
RIM-MOUNTED SECONDARY SEAL
FLOATING ROOF
SCUFF BAND
LIQUID-FILLED TUBE

a. Shoe seal with rim-mounted secondary seal.

b. Liquid-filled seal with rim-mounted secondary seal.


TANK WALL
RIM-MOUNTED SECONDARY SEAL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG
VAPOR SPACE
TANK WALL
RIM-MOUNTED SECONDARY SEAL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG

c. Resilient foam seal (vapor-mounted) with rim-mounted secondary seal.

d. Resilient foam seal (liquid-mounted) with rim-mounted secondary seal.

Figure 4-4. Rim-mounted Secondary Seals on External Floating Roofs. Source: Erikson, 1980 (Reference 3).

Secondary seal systems employed on the external floating roof tanks are quite important, as they provide weather protection to the seal. There are two types of systems employed: roof-mounted, or seal-mounted, as shown in Figures 4-4 and 4-5.

The primary considerations involved in selecting an appropriate seal system for an external floating roof tank are the type of material being stored (compatibility with seal materials), size of gap between roof and wall, tank design (interior reinforcements, tank wall imperfections, and tank weight capacity), weather conditions, and floating roof design.

Internal Floating Roof Tank Seals--[2]

Internal floating flexible roofs typically incorporate one of two types of flexible primary seals: resilient foam-filled seals, or wiper seals. The foam-filled seals are the same as the type used for external floating roof tanks. Wiper seals, which are the more common type, are simple systems in which a flexible membrane is used to cover the gap between the roof and the tank wall. These types of seals are usually vapor-mounted and are either continuous (one piece extending around the perimeter), or shingled (overlapping segments extended around the perimeter). Secondary seals are less common for internal floating roof tanks. The considerations involved in selecting an appropriate seal system for internal floating roof tanks are the same as for external floating roof tanks, although weather consideration are much less significant due to the fixed roof cover.

Vents--

All fixed roof tanks must be equipped with some type of venting system. Tank vents serve as a protection against structural damage to the tank caused by a buildup of vapor inside the vapor space, by releasing them to the atmosphere. Vents may be installed in the roof or the tank walls (above the maximum liquid level). Many types of vents are used, ranging in sophistication from simple open vents to pressure-vacuum systems equipped with flame and flash arrestors. The most common venting system used on tanks is a conservation vent, which is described in detail below.[5] In general, vents

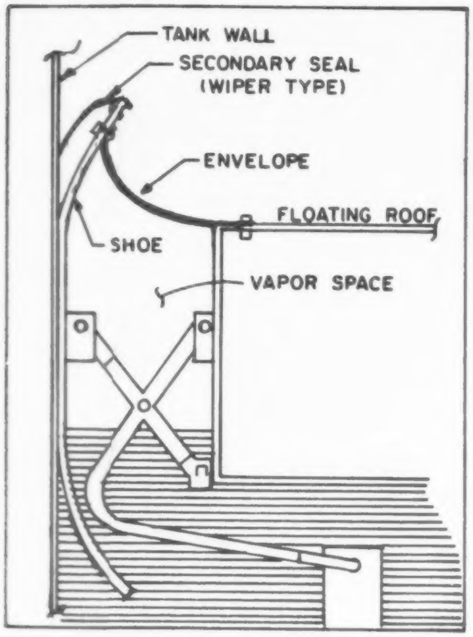

TANK WALL
SECONDARY SEAL (WIPER TYPE)
ENVELOPE
FLOATING ROOF
SHOE
VAPOR SPACE

Figure 4-5. Metallic Shoe Seal with Shoe-Mounted Secondary Seal.
Source: Erikson, 1980 (Reference 3).

are applicable to any tank with a fixed roof. The choice of a vent is dependent upon tank design and the volatility of tank constituents.

Conservation Vents--

A conservation vent is defined as a system which is designed to release vapors from a storage tank once the internal pressure reaches a predetermined point. The set point is based upon the structural characteristics of the tank. A conservation vent furthermore serves to prevent the inflow of air and the formation of a vacuum inside the tank. There are three basic designs of conservation vents: diaphragm, liquid-seal, and metal-to-metal.[4] Metal-to-metal seals have found the most widespread usage. The primary considerations involved in selecting an appropriate conservation vent are the volatility and flammability of the material, tank design, and vent location.

Emission Reduction Effectiveness

The general effectiveness of storage tank roofs in controlling emissions is considered to be be high. The extent to which emissions from an existing tank can be reduced depends upon the design chosen. A fixed roof is capable of reducing emissions from open tanks or external floating roof tanks by anywhere from 0 to 90 percent depending upon the volatility of the material being stored, and the use of conservation venting or insulation. A floating roof is capable of reducing emissions from open or fixed roof tanks by up to 99 percent depending upon the use of primary or secondary seals, venting, and drainage. Installing secondary seals on a floating roof with an existing primary seal may result in reductions between 60 to 90 percent depending on the interior design constraints. Conservation vents have produced emission reductions of up to 90 percent in fixed roof tanks.

Costs

The installation of a new tank, new roof, or associated system is considered to be a highly expensive. The high costs involved are largely based on capital costs (materials) and construction, and the associated design work needed. The costs vary according to the size requirements, materials used, and input and output considerations.

Fixed roof tanks are the most widely varied design in terms of costs. Simple fixed roof tanks of small dimensions are relatively inexpensive, while high pressure tanks are the most expensive. Costs are dependent upon the materials used, and the structural support considerations. Retrofitting a fixed roof onto an existing tank is considered to be essentially as expensive as constructing a new tank. Estimated costs (1980) for fixed roof tanks are shown in Table 4-2.[3] In March 1985 dollars, fixed roof tank costs range from $36,000 to $281,000 for the size range indicated.

Floating roof tanks are somewhat more expensive to build than fixed roof tanks, due to greater complexity involved in the roof design. Installation of a floating roof on an existing tank, however, is much simpler and less expensive than is the installation of a fixed roof due to their simpler design and structural considerations. The costs of a floating roof are dependent upon the design selected, materials, installation, and maintenance requirements (more maintenance is required for floating roofs than for fixed roofs). Table 4-3 presents construction costs for external floating roof tanks. In March 1985 dollars, these costs range between $55,700 and $295,000.

Estimated costs (1980) of installing an external floating roof with primary seal for contact and noncontact designs are shown in Tables 4-4 and 4-5.[3] In March 1985 dollars these costs range from $7,800 to $57,800 for contact roofs, and $6,300 to $41,800 for noncontact roofs.

The costs involved in installing a seal system on a floating roof are dependent upon the design selected, materials, installation, and maintenance requirements. MITRE estimated that the typical cost of retrofitting a (secondary) seal system would range from $29 to $38 per linear foot of circumference.[6]

Conservation vents are the least expensive of the options described in this section, due to their relative design simplicity and ease of installation. MITRE estimated that a typical vent may cost between $540 to $4,300 (in present day value) or approximately $0.01 to $0.09 per gallon of capacity.

TABLE 4-2. COST OF BUILDING A FIXED-ROOF TANK[a]

Diameter (ft)	Height (ft)	Installed cost[a]
20	24	26,000
40	40	63,000
45	40	73,000
50	40	89,000
60	40	113,000
70	40	139,000
80	40	168,000
90	40	202,000

[a] Costs in first quarter 1980 dollars.

Source: Erikson, 1980 (Reference 3).

TABLE 4-3. COST OF BUILDING AN EXTERNAL FLOATING ROOF TANK

Diameter (ft)[a]	Height (ft)	Installed cost[b]
30	24	40,000
35	30	54,000
42.6	40	81,000
52	40	117,000
60	40	126,000
67	40	140,000
73.4	40	153,000
100	40	212,000

[a] Cost of adding a secondary seal per foot of circumference is $13.50.

[b] Costs in first quarter 1980 dollars.

Source: Erikson, 1980 (Reference 3).

TABLE 4-4. COST OF INSTALLING A CONTACT SINGLE SEAL INTERNAL FLOATING ROOF

Diameter (ft)[a]	Installed cost ($)[b]
15	5,630
20	6,485
25	7,510
30	8,780
35	10,280
40	11,970
45	14,180
50	16,190
55	19,630
60	21,480
65	25,120
70	27,770
75	31,240
80	34,360
85	37,910
90	41,530

[a] Cost of adding a secondary seal, per foot of circumference is $11.85.

[b] Costs in first quarter 1980 dollars.

Source: Erikson, 1980 (Reference 3).

TABLE 4-5. COST OF INSTALLING A NONCONTACT SINGLE SEAL INTERNAL FLOATING ROOF

Diameter (ft)[a]	Installed cost ($)[b]
15	4,500
20	6,000
25	7,300
30	9,300
35	10,000
40	12,000
45	13,300
50	14,700
55	16,500
60	17,400
65	19,700
70	21,500
75	23,500
80	25,200
85	27,800
90	30,000

[a] Installed cost of adding a secondary wiper seal per foot of circumference is $22.50.

[b] Costs in first quarter 1980 dollars.

Source: Erikson, 1980 (Reference 3).

COVERS

Introduction

A cover is defined as any system which limits or prevents the volatilization of material from a storage tank by acting as a barrier between the volatile substances and the atmosphere. Covers, unlike roofs, are not designed to be permanently affixed to a storage tank. Such systems, therefore, are generally applied only to open or fixed roof tanks. A wide variety of covers are available. Covers which have found application as storage tank emission control devices include:

- Floating blankets;
- Floating spheres;
- Rafts;
- Surfactant layers; and
- Nitrogen blankets.

Use of covers for storage tanks is not as prevalent as that of roofs for controlling emissions.[1] This subsection will present examples of systems which are in use or have been proposed for use at TSDFs.

Description

A cover serves to limit the emission of volatile substances from storage tanks by acting as a barrier to volatilization, reducing volatility, and/or insulating the substances from external forces such as heat, light, wind, and precipitation, which serve to increase volatilization. All covers are applied such that much of the liquid surface area is covered. Covers can either be placed directly upon the liquid surface, on floats or pontoons just above the liquid surface, or over the top of (open) tanks. The following considerations must be made in determining the applicability of a cover system to a specific storage tank at a TSDF.

- Type of material to be stored. The chemical and physical properties of the material to consider include, volatility, chemical compatibility, and density.

- Design of storage tank. The diameter, weight capacity, inflow/outflow pipe locations, and interior structural design (e.g., of columns or bracings) of the tank.

- Storage procedures. The tank turnover rate (number of times emptied and filled per year), tank usage, filling procedures, and tank level preference are among the procedural factors.

- Weather conditions. Wind, sun, and precipitation patterns of the local area.

- Manpower requirements. The availability of trained personnel for maintenance or operating procedures.

All cover systems contain certain limitations which must be evaluated against factors such as emission reduction efficiency, cost, and ease of implementation. The cover systems introduced above have been demonstrated to be the most applicable to storage tank emission control according to the above criteria.

Floating Blankets--

Floating blanket covers perform similarly to pan-type floating roofs. Resting directly upon the liquid surface, the flat covers apply pressure to the liquid, thus eliminating vapor space and reducing breathing losses. As the tank is filled and emptied, the cover rises and falls, thus reducing working losses. Floating blankets are usually made from lightweight synthetics, such as polyvinyl chloride. The blanket underside is constructed of a large number of floats made from the same plastic material.[2] The blankets are commonly made so that only a very small gap will remain around the periphery. Most floating blanket systems also employ a vertical skirt around the edge to serve as a vapor seal over the annular area.[5] Design features to be considered in selecting the most appropriate floating blanket design are the size and shape of the surface to be covered, the chemical compatibility and vapor permeability of the synthetic material, the drainage of liquid from the top of the cover, and the system weight.

Floating blankets present certain advantages over a floating roof design. They are lightweight, more flexible, will not sink, warp, or corrode, and are removable. To date, these systems have found greater application in foreign markets.[5]

Floating Spheres--

Another way that lightweight plastic materials are used as a cover is in the form of hollow plastic spheres. Floating spheres also perform similarly to pontoon roofs, although they are far more fluid. Floating spheres will cover approximately 90 percent of the available surface area, independent of the sphere diameter. Because they are hollow, they will also act as dead air insulators. Floating spheres are commonly made from either high molecular weight polyethylene or polypropylene.[1] Size ranges vary from microscopic to 6 inches in diameter.[5,7] Common designs employ an antirotational collar so that the spheres will interlock over the liquid surface and will not be subject to natural or forced convection currents turning the wet sides of the spheres to the air. (See Figure 4-6.)

Normally, only one layer of spheres is used to cover the liquid surface.[1] In certain cases, however (e.g., for highly toxic and/or volatile substances), more than one layer is used. It has been demonstrated, that each successive layer of spheres added is less effective, as the added weight increasingly submerges the bottom layer.[7] The considerations involved in selecting the appropriate floating sphere cover are the diameter of the tank, the size of the spheres, the number of layers, and the spheric material. Floating spheres have several advantages over roofs or other cover systems. They are more fluid and can, therefore, be used in any tank, they are good insulators, will not sink, need no drainage system, and are removable. Floating spheres have found a variety of applications including crude oil waste storage, solvent storage, and at a European wastewater treatment plant.[7]

Rafts--

A raft is defined as any device which floats freely upon the liquid surface. Rafts perform similarly to pan-type floating roofs. Rafts are available in two designs, including foam blocks (the most common type) and

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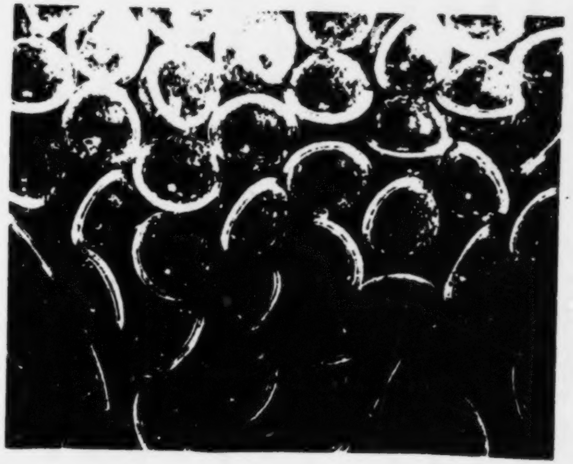

Figure 4-6a. Interlocking configuration.

Figure 4-6b. An uncovered cleaning tank emits large volumes of corrosive acid steam.

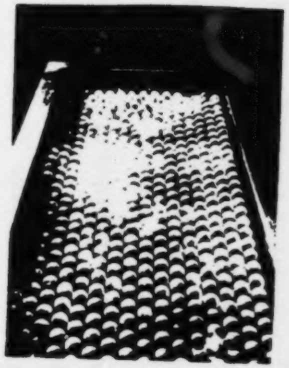

Figure 4-6c. A single layer of ALLPLAS balls floating on the surface of the same temperature, virtually eliminates acid steam emission.

Source: Capricorn Chemicals.

membranes attached to a frame. An example of the foam block system is shown in Reference 9.

A raft can be made from any kind of material. Styrofoam, polyethylene, aluminum bonded to polyethyelne, butyl rubber, and floating concrete have all been field tested.[8] A raft can be made in any shape or thickness.[9] Several rafts may be used on one surface. They are easily installed and maintained. Many rafts are coated with reflective material to decrease their transmissivity of heat to the liquid.[1]

The considerations involved in selecting an appropriate raft design are the size and shape of the tank, chemical compatibility, raft insulating capacity (related to thickness and color), number of rafts to be used, and the drainage system. Rafts have the advantage of being lightweight, easy to install and maintain, buoyant, nonwarping, and removable. Rafts have found only limited application as a storage tank cover system, but have been used extensively on surface impoundments.

Surfactant Layer--

A layer of liquid with which the volatile substances in storage are immiscible may be applied as a cover. A floating liquid cover serves to limit emissions in much the same way as other floating covers. As long as the layer is maintained, volatiles can only be released if they diffuse through the liquid barrier. The choice of a particular liquid for this application is strongly dependent upon the materials being stored. Among those materials cited in the literature were water (used in the storage of ethylene dichloride)[10] and lubricating oil (acrylonitrile wastewater).[11] In such a system, no vapor seals or drainage systems are needed.

The considerations involved in selecting a liquid cover system are chemical compatibility, weather conditions, and layer regeneration method. Use of a surfactant layer can be desirable due to the adaptability to any shape or size tank, the completeness of coverage with no required appurtenances, and the ease of implementation. The use of such a system, however, has been quite limited.[11]

Nitrogen Blanket--[6]

Nitrogen, or any other inert gas, may be maintained in the vapor space of a tank as a cover system. Nitrogen blanketing works to control emissions by applying a slight positive pressure in the tank, thus inhibiting volatilization. Like a surfactant layer, a nitrogen blanket acts as an ultimately adaptable floating roof. Nitrogen blankets are mainly applicable to fixed roof tanks. A small generating unit is required, to maintain the blanket. Application of nitrogen is limited by the internal pressure constraints in the tank.

The considerations involved in such a system are the design of the tank, chemical compatibility, operation of nitrogen generators, and weather conditions (particularly, temperature fluctuations). Nitrogen blankets are especially applicable to highly reactive, highly volatile substances. Overall, nitrogen blankets have the advantage of adaptability, completeness of cover, inertness, and low equipment cost and maintenance.

Emission Reduction Effectiveness

In general, covers are expected to be a relatively effective means of emission control. The effectiveness of such control systems has not be studied in detail, due to constraints encountered in making emission tests on tanks. The extent to which emissions from any tank may be reduced by a specific cover system is highly dependent on the tank design (in particular, the diameter and the structural characteristics), and the tank constituents.

In general, those cover systems which are the most flexible, limit available liquid surface area the most, and are least subject to wind, and other weather conditions will perform best. Thus, while floating spheres might reduce emissions up to 90 percent,[1] a floating surfactant layer, which is subject to being dissipated by wind, might only reduce emissions by 25 to 75 percent.[6] Nitrogen blanketing is estimated to be potentially the most effective cover system, ranging from 50 to 99 percent[6] reduction efficiency. Rafts, similar in performance to floating spheres and blankets, are estimated to range up to 90 percent in effectiveness.[1] These estimates are approximate. Other data accumulated by Cooley are presented in Table 4-6.[8] The basis of these estimates is the percentage of surface area covered, and the vapor permeability of the covers. Covers are not expected to

TABLE 4-6. EVAPORATION REDUCTION ACHIEVED BY VARIOUS ENERGY-REDUCING METHODS

Method	Area of water surface covered, as a percentage	Evaporation reduction, as a percentage
1. Changing the water color:		
Dye in water	100	6-9
Shallow, colored pans	100	35-50[a]
2. Using wind barriers:		
Baffles	-	11
3. Shading the water surface:		
Plastic mesh	47	44
Blue polylaminated plastic sheeting	100	90
4. Floating covers:		
Perlite ore	78	19
Polystsyrene beads	78	39
Wax blocks	78	64
White spheres	78	78
White butyl sheets	86	77
Polystyrene sheets	80	79
Polystyrene rafts	100	95
Polystyrene wax	100	87
Foamed rubber	95	90

[a] Evaporation from white pan compared with that from black pan.

Source: Cooley, 1983 (Reference 8).

perform as effectively as either vapor control systems or roofs, but are less costly and easier to implement at an existing facility.

Costs

Cover systems are generally considered to be less expensive than roof systems to implement at a storage tank facility. The costs of such systems are strongly dependent upon the cost of materials and maintenance. Labor, operation, and installation costs are considered to be relatively low.[1] Detailed cost estimates are highly dependent upon various design and materials considerations (tank sizes, cover materials, etc.).

The cost of floating blanket covers is primarily dependent upon the synthetic material selected. The estimated average cost of a synthetic cover (as applied to a surface impoundment) is $1.48 to $3.26 per square foot.[6] (1985 dollars).

Floating spheres are available in a variety of sizes, and basically two materials, polypropylene and polyethylene. The number of balls required for coverage of a storage tank can be determined by geometry. Table 4-7, provides some example requirements. Table 4-8 shows that the estimated average cost for a cover of floating spheres ranges from $4.65 to $13.50 per square foot of internal surface area.[6]

Cost of raft system would be similar to floating sphere system, as both only involve materials costs. A typical foam block raft system was estimated at $130 to $210 for a medium size facility (25 ft diameter).[1]

The cost of a surfactant layer is dependent upon the surfactant chosen, and application procedure. Cost is regarded as a primary factor in the choice of a surfactant chemical for this application. MITRE estimated a cost of 0.09 cents per square foot (updated to 1985 dollars) for similar application on a surface impoundment.[6]

The cost of a nitrogen blanketing system is dependent upon nitrogen consumption (dependent on tank capacity), and costs of nitrogen storage and delivery equipment. The estimated annual installed cost of such a system is $0.11 to $0.33 per gallon of tank capacity (Updated to 1985 dollars).[6]

TABLE 4-7. NUMBER OF FLOATING SPHERES REQUIRED PER UNIT AREA AND VOLUME

Spheric size/ Quantity	20 mm (3/4 in.)	38 mm (1-1/2 in.)	45 mm (1-3/4 in.)	150 mm (6 in.)
Quantity/m^2	2.500-3.000	750-800	500-575	45-50
Quantity/ft^2	230-280	75-85	45-55	4-5
Quantity/m^3	165.000-167.000	24.500-25.000	14.500-15.000	350-400
Quantity/ft^3	4.670-4.730	690-710	410-425	10-11

Source: Capricorn Chemicals, 1985. (Reference 7).

TABLE 4-8. COSTS OF VARIOUS TYPES OF FLOATING SPHERES

	Cost ($/ft^2)
Polypropylene	
Diameter 1-3/4 inches	4.65-6.55
Diameter 6 inches	7.50-8.69
High Density Polyethyelne	
Diameter 1-3/4 inches	6.75-7.55

Source: A. D. Little, 1984 (Reference 1).

INSULATION

Introduction

Any system or device which serves to reduce the effects of climatological forces such as sunlight, ambient temperature fluctuation, wind, and precipitation on storage tanks and tank constituents may be defined as a tank insulation system. These forces serve to increase tank breathing losses by increasing the volatility of constituents and/or by providing a transport mechanism for emissions to enter the atmosphere. Insulation systems are highly simplistic in design, and as a result, have found widespread application.[5] Most storage tanks are insulated in some way. The three methods of tank insulation which have found the most widespread application are:

- Thermal insulation;
- Reflective paint; and
- Wind barriers.

Description

Insulation systems form a barrier to the external forces described above. Each of the insulation systems can be applied directly to the storage tank, require little to no additional maintenance, and occupy very little space.[6] The following considerations must be made in selecting the appropriate insulation system.

- Weather conditions. The affect of extreme heat, wind, or precipitation on the insulation system.
- Storage tank design. The height, shape, and diameter of the tank may.
- System design. The weight, height, and other complexities of the insulation system.

- Storage area. The area layout, and space for the insulation system.

Thermal Insulation--

Thermal insulation systems may be applied to the sides and tops of storage tanks. The insulation material serves to reduce the temperature fluctuation of storage tank constituents, even when ambient conditions vary. Various types of systems are employed, including both flexible and rigid polymeric foam, and vermiculite concrete.[5] The most common materials in use at TSDFs are spray-applied polyurethane foams and rigid polystyrene foams.[12] Design considerations involved in selecting a thermal insulation material are the available surface area to be covered, tank wall material (ease of applying insulation), weather conditions, insulation thickness, and the total applied weight of the system.

Fresh Painted Tanks--

Fresh paint may also be applied to the sides and tops of storage tanks. New paint will have the effect of reducing emissions by providing a better more reflective outer surface. The two colors most commonly applied to storage tanks are white and silver.[5] A painted tank has been demonstrated to emit less than an identical unpainted one (see Table 4-9). The factors which are to be considered in selecting a new paint for storage tanks are the chemical compatibility of paints with emitted materials, maintenance requirements and, most importantly, sun conditions.

Wind Barriers--

Wind barriers are devices installed on or around storage tanks which serve to reduce the flow of wind affecting a tank. Wind increases storage tank emissions by three mechanisms, including: (1) increasing surface turbulence inside a tank (particularly in the case of open tanks), leading to greater volatilization of liquid; (2) sweeping vapor out of a storage tank as wind flows over or through the tank vapor space; and (3) creating a pressure differential leading to emissions via forced convection as wind flows over a tank or tank vent.[4] Barriers may be installed on a tank or around a tank. The most common design is a barrier installed at the top of a tank, around the

TABLE 4-9. RELATIVE EFFECTIVENESS OF PAINTS IN KEEPING TANKS FROM WARMING IN THE SUN (NELSON, 1953).

Color	Relative effectiveness as reflector or rejector of heat (%)
Black	0
No paint	10.0
Red (bright)	17.2
Red (dark)	21.3
Green (dark)	21.3
Red	27.6
Aluminum (weathered)	35.5
Green (dark chrome)	40.4
Green	40.8
Blue	45.5
Gray	47.0
Blue (dark Prussian)	49.5
Yellow	56.6
Gray (light)	57.0
Aluminum	59.2
Tan	64.5
Aluminum (new)	67.0
Red iron oxide	69.5
Cream or pale blue	72.8
Green (light)	78.5
Gray (glossy)	81.0
Blue (light)	85.0
Pink (light)	86.5
Cream (light)	88.5
White	90.0
Tin plate	97.5
Mirror or sun shaded	100.0

Source: AP-40 (Reference 5).

perimeter.[14] Various types of barriers are used for this purpose, including "cyclone" fences; corrugated steel walls, and other, more complex designs.

Wind barriers are particularly applicable to open or external floating roof tanks. They have not found widespread use at TSDFs for control of air emissions from storage tanks, however. The considerations involved in selecting a wind barrier system for storage tank control are the tank structural requirements, prevailing wind conditions (direction, magnitude), availability of space, and the height and design of the barrier.

Emission Reduction Effectiveness

Insulation systems are simple, and easy to install. However, the effectiveness of such systems in reducing emissions, however, is relatively low (compared to other add-on controls). This is primarily due to the fact that they are chiefly designed to reduce breathing losses, which are generally not as significant as working losses. Information on the effectiveness of such controls is also limited.

Thermal insulation systems are generally quite effective in reducing, if not eliminating, thermal fluctuations. The effectiveness of such systems is dependent upon the thickness of the insulation layer, and amount of tank area covered. Insulation effectiveness is also limited by the "gradual absorption and permeation of moisture through the insulation. (See Table 4-10). The thermal performance of several insulation materials is shown in Table 4-11. MITRE estimated that the effectiveness of insulation in emission reduction ranges from 50 to 99 percent.[6]

The application of reflective paint is limited in its effectiveness as an emission reduction technique. As shown previously in Table 4-9, effectiveness varies widely with paint color. However, since the paint itself is a relatively thin layer, heat energy will be transmitted to the tank. AP-40 reported that the emission reduction achieved, for example, by use of aluminum paint (over black paint) was 25 percent based on data gathered by the American Petroleum Institute.[5]

Wind barriers have been used in many different ways (see Sections 5 and 8 in the document) at TSDFs. The effectiveness of such devices depends strongly

TABLE 4-10. PERMEABILITY AND MOISTURE ABSORPTION

Insulation material	Permeability Perm . Inch[a]	Absorption % by Vol.
FOAMGLAS®	0	0.2[b]
Urethane	1-3	1.6
Polystyrene	0.5-4	0.7
Phenolic	6-7	10.0
Fiberglass	75	65.0
Mineral fiber	150	70.0
Calcium silicate	NA	75.0
Expanded perlite	NA	16.0

[a] Perm . Inch is the accepted unit of water vapor permeability.

$$1 \text{ Perm} \cdot \text{Inch} = \frac{1 \text{ Grain . Inch}}{\text{Ft}^2 \text{ . Hr . Inch of Mercury}}$$

[b] The only moisture retained is that adhering to surface cells after immersion.

Source: Pittsburgh Corning Corporation, 1985 (Reference 15).

TABLE 4-11. PUBLISHED THERMAL PERFORMANCE

Insulation material	Maximum use temp. (°F)	Thermal conductivity Btu·In./Hr . F . Ft^2 -100	+200
FOAMGLAS	900[a]	0.27	0.42
Urethane	200-225	0.14	0.25
Polystyrene	175	0.18	NA
Phenolic	250	0.19	0.26
Fiberglass	450	0.16	0.30
Mineral fiber	1800	NA	0.35
Calcium silicate	1200	NA	0.42
Expanded perlite	1500	NA	0.47

[a] Limitation when used alone.

Source: Pittsburgh Corning Corporation, 1985, (Reference 15).

on prevalent wind patterns. While no direct measurements have been published relative to the emission reduction effectiveness of wind barriers for storage tanks, Runchal estimated that the reduction effectiveness would range from 22 to 50 percent.[13]

Costs

The costs of insulation systems are generally regarded as being low, relative to other add-on control systems. The costs generally involve only materials and installation.

Thermal insulation costs vary widely depending on the materials used. Costs are also dependent upon the thickness and percentage of surface area covered. Based on estimates made by MITRE,[6] the cost of thermal insulation ranges from $0.65 to $0.76 per inch thickness per square foot of tank area, plus an additional $1.00 to $1.25 per square foot for protective coating.[6]

Painting costs are also widely variable. The costs depend on the type of paint selected, application method, and labor costs. In general, painting is regarded as a low-cost measure to effect control. A representative of Chevron USA Inc. estimated that the average storage tank paint job costs between $500 and $3,000 per tank.[14]

Wind barrier costs are also regarded as being relatively low. These costs depend upon the type of fence selected, height of fence, and installation labor. An estimate of the cost of wind screens (as applied to waste piles) is $2.00 to $2.50 per square foot of fence area (1982 dollars).[6]

VAPOR CONTROL SYSTEMS

Introduction

Vapor control systems control the emission of volatile substances from storage tanks by evacuating vapors which form, and processing them physically or chemically. Vapor control systems are the most complex and costly of storage tank controls, but are the most effective at reducing emissions. Use of vapor control on storage tanks is widespread, particularly in chemical processing.[1] The three vapor control systems which are most commonly used for storage tank emission control are:

- Vapor condensation;
- Carbon adsorption; and
- Fume incineration.

Description

The primary function of a vapor control system is to remove vapors which form in a storage tank, by some physical or chemical process such that they will not enter the environment. Such systems are equally effective at controlling working or breathing losses, as any vapor which forms is evacuate from the tank. All vapor control processes contain at least three steps:

(1) evacuation;
(2) vapor processing; and
(3) recycle or venting of products.

Use of vapor control requires that the storage tank be enclosed in some manner. Thus, vapor control is applicable only to tanks equipped with fixed roofs. Vapor control systems require the installation of ductwork, the location of unit processing equipment in readily serviceable areas, and equipment for disposing of products and materials. Vapor control has found widespread application, particularly in the control of highly volatile and/or toxic substances, due primarily to the high emission reduction efficiencies that can be achieved. While the system designs may be relatively complex, the unit processes are simple, utilizing physical or chemical properties such as the vaporization point, adsorbability, or combustibility. The following factors should be considered when determining the applicability of a particular vapor control system to a certain storage tank or tanks.

- Properties of the tank constituents including the volatility, adsorbability on carbon or other substrates, and combustibility.
- Number of tanks to be serviced and the total capacity to be served by the vapor control system.
- Manpower and materials requirements including maintenance, operating labor, and materials required by the vapor control system.
- Availability of space which would affect the location of the vapor processing unit, and attendant ductwork and systems.

The three most common vapor control systems, described in detail below, have found widespread application.

Vapor Condensers--

Vapor condensation systems prevent emissions of volatile substances by recondensing vapor which form in a storage tank. Condenser systems are the most widely used form of vapor control for storage tanks.[5] Condensers work by extracting heat from the vapors either by contacting them with a coolant (contact-type) or with a cooled surface (surface-type). Contact-type condenser are not generally used for control of TSDF emissions, due to chemical compatibility and waste handling considerations. The most common type of condenser is the "shell and tube" type, as shown in Figure 4-7. In this system, vapors are passed through a chamber which contains thin tubes. Coolant is passed through the tubes, and cools the metal surfaces, which in turn cool the vapors as they flow around the tubes. A variety of coolants are used, depending upon the volatilization point of the vapors, including chilled water, air, or freon.[3]

Shell and tube condensers are commonly oriented horizontally, but some designs orient them vertically. Coolant flow can either be countercurrent or concurrent with vapor flow direction. It is common to install baffles in the shell side of a condenser, or to design the condenser with more than one chamber (pass), in order to increase the contact time between vapors and tubes.

The considerations involved in selecting an appropriate condenser system for control of storage tanks are the operating temperature range, coolant type, number of condenser tubes, baffles or passes, refrigerant storage and handling, and condensate and vapor recycle or handling. Condensers have

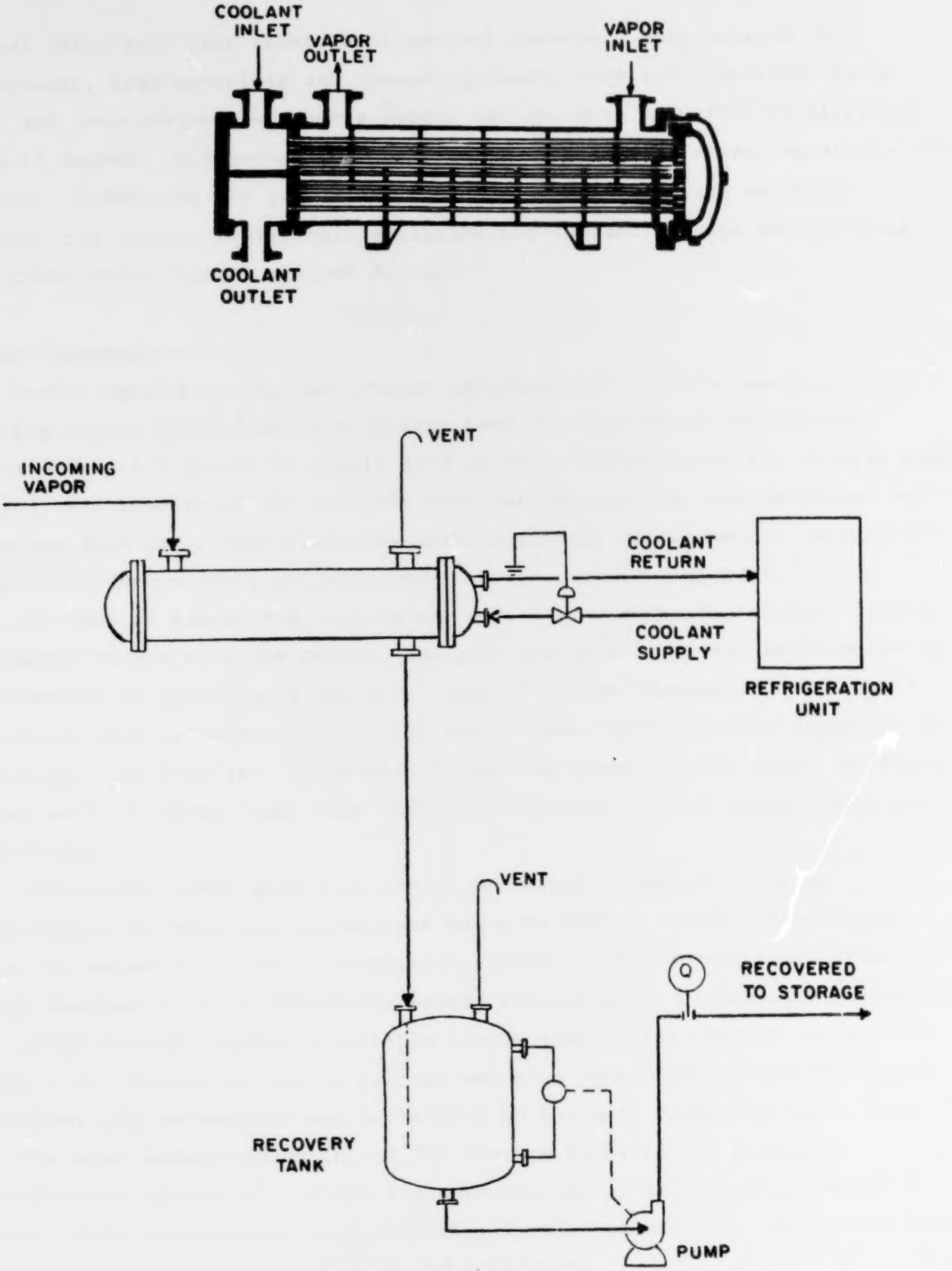
COOLANT INLET
VAPOR OUTLET
VAPOR INLET
COOLANT OUTLET
VENT
INCOMING VAPOR
COOLANT RETURN
COOLANT SUPPLY
REFRIGERATION UNIT
VENT
Q
RECOVERED TO STORAGE
RECOVERY TANK
PUMP

Figure 4-7. Refrigerated Vent Condenser System.
Source: Erikson, 1986 (Reference 3).

several advantages over other vapor control systems. They require less maintenance, less materials and operating costs, they are considered to be safer and less subject to process upset, and are more adaptable to different types of vapors. A condenser can be used to selectively recover materials, if desired. Condensers are generally less effective in reducing emissions, however, and require additional facilities for coolant storage and handling that other vapor control systems do not.

Carbon Adsorption--

Carbon adsorption systems prevent emissions of volatile substances by removing vapors which form in a storage tank via adsorption onto carbon. Carbon adsorption is not as widely used as vapor condensation for storage tank control, but have found use at TSDFs both for controlling tank emissions and emissions from other unit processes such as surface impoundments. Adsorption devices utilize carbon's affinity for nonpolar organic compounds.[3]

As shown in Figure 4-8, vapors are passed over beds of activated carbon. The vapors adsorb onto the carbon, and exit the beds to either be recycled to the adsorber or vented as clean air. Gradually, the adsorption capacity of the carbon beds is reduced, until the beds become saturated with organic. At that point, the beds are regenerated by passing steam through them. Multiple carbon beds are often used, such that some beds may be used while others are regenerated.

Adsorption system generally employ activated carbon, but recent advancements in resin adsorption have begun to result in their increasing usage for emission control. Adsorption systems range in complexity from simple designs in which vapors are passed through drums filled with carbon, to full scale systems employing multiple carbon beds as illustrated in Figure 4-8. Adsorption can be carried out as a single-pass or multiple-pass operations and carbon beds may be baffled to increase vapor residence time.

The most common system in use for storage tanks is the simple "barrel"-type adsorbers[6]. These are used because it is considered safer to control tanks individually than collectively (interconnected tank systems are subject to increased risks of fire and explosion).

The considerations involved in selecting an appropriate carbon adsorption system for control of storage tanks are the operating temperature range,

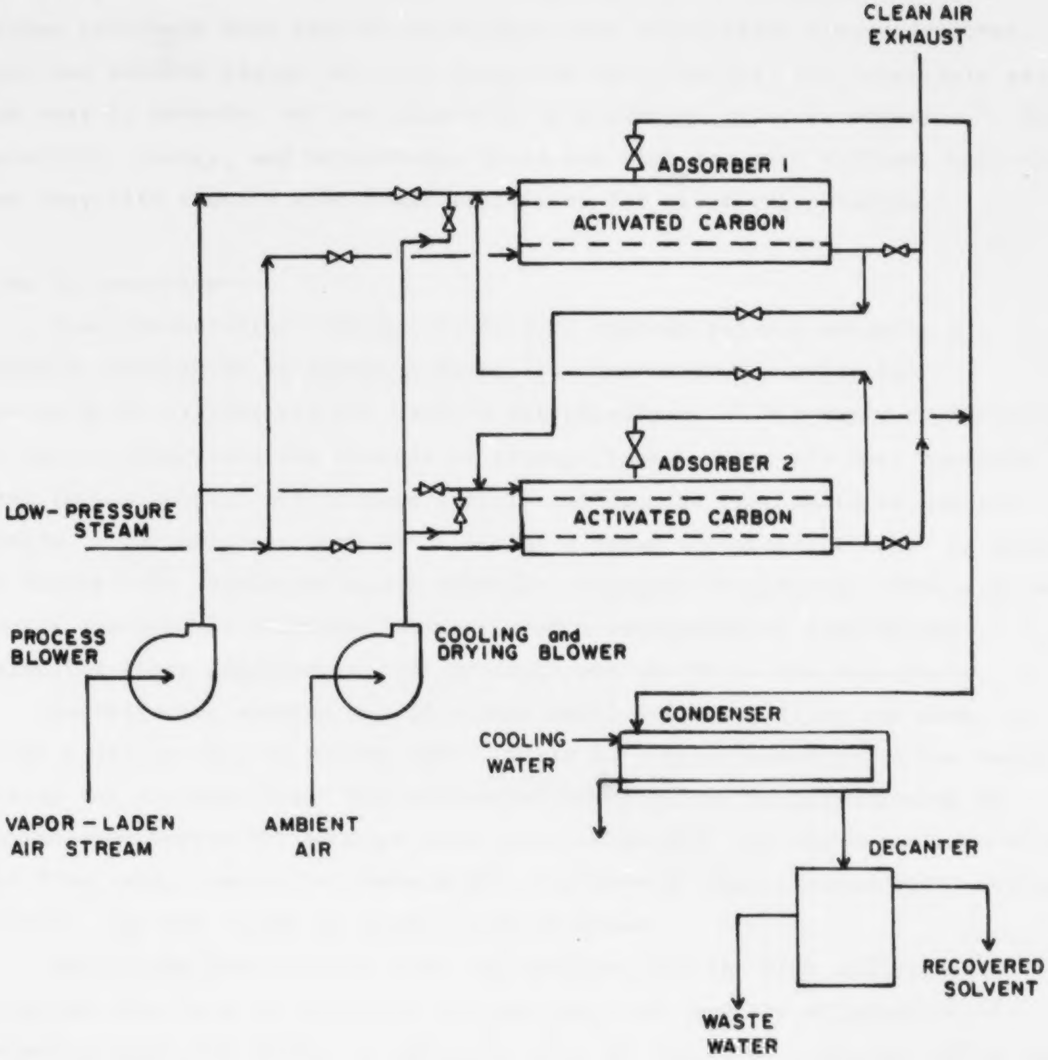
CLEAN AIR EXHAUST
ADSORBER 1
ACTIVATED CARBON
ADSORBER 2
ACTIVATED CARBON
LOW-PRESSURE STEAM
PROCESS BLOWER
COOLING and DRYING BLOWER
VAPOR – LADEN AIR STREAM
AMBIENT AIR
CONDENSER
COOLING WATER
DECANTER
RECOVERED SOLVENT
WASTE WATER

Figure 4-8. Activated-Carbon Adsorption System.
Source: Erikson, 1980 (Reference 3).

chemical compatibility and adsorbability of materials, number and sizing of beds, regeneration and adsorbate handling systems, and carbon life span. Carbon adsorbers have several advantages over other vapor control systems. They can achieve higher emission reduction efficiencies, are relatively safe and easy to operate, and are adaptable to different volatile organics.[6] The materials, energy, and maintenance costs are high for such systems, however, and they also require additional facilities for steam regeneration.

Fume Incineration--

Fume incineration (thermal oxidation) systems prevent emission of volatile substances by changing materials chemically via oxidation. Incineration systems are not used as extensively as either vapor condensation or carbon adsorption for control of storage tanks. They are most commonly used in combination with a more significant process vent emission control system.[3] Incinerators work by utilizing a vapor's combustibility. As shown in Figure 4-9, vapors are mixed with air, injected to a burner where a pilot source ignites the air-vapor mixture, and a supplementary fuel burner maintains flame temperature, and products are vented to the atmosphere.

Incineration systems may be either small units servicing one tank, or large units serving an entire TSDF. There is little variation in the basic design for incinerators. The considerations involved in implementing an incinerator system for storage tank emission control are the vapor composition and flow rate, combustion temperature, incinerator fuel, incinerator venting control, and the number of tanks to be serviced.

The advantages of using fume incineration are the high efficiencies achieved, the lack of attendant systems required, and the elimination of volatile compounds (thus, no emissions will be caused by compounds which are recovered). However, incineration requires high operating costs (due to energy consumption and greater safety risks.

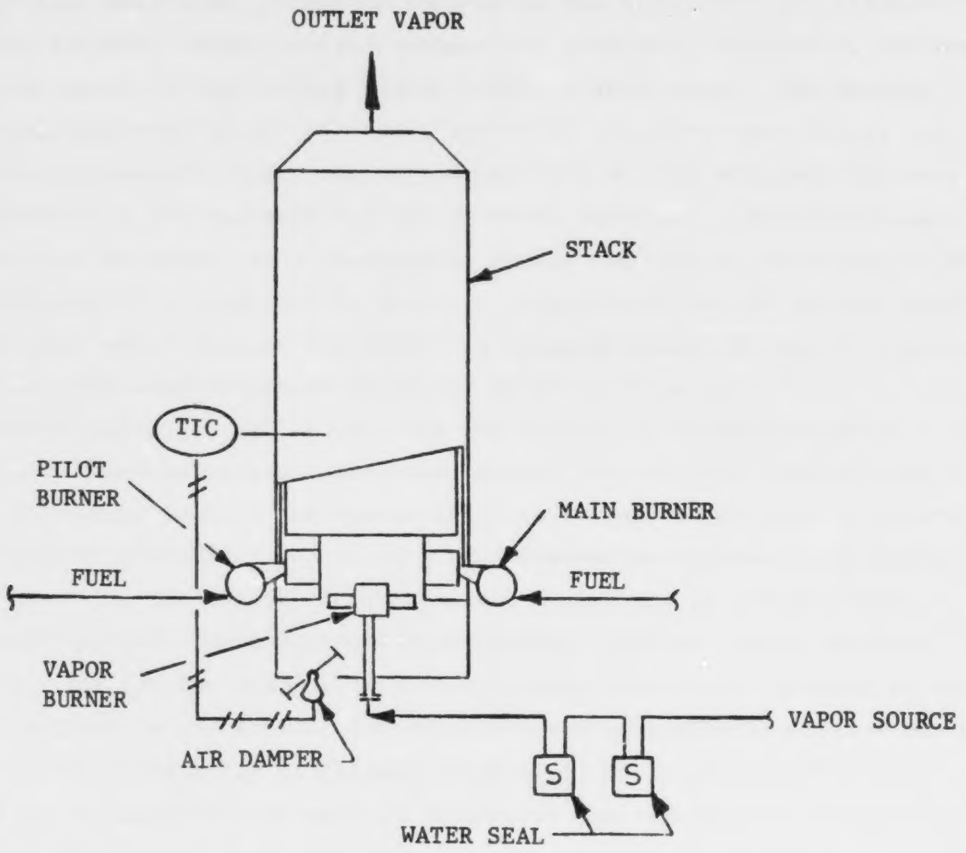
OUTLET VAPOR
STACK
TIC
PILOT BURNER
MAIN BURNER
FUEL
FUEL
VAPOR BURNER
AIR DAMPER
VAPOR SOURCE
S
S
WATER SEAL

Figure 4-9. Thermal oxidation unit.

Source: Erikson, 1980 (Reference 3).

Emission Reduction Effectiveness

Vapor control systems have found widespread application for control of storage tank emissions, primarily because of the high reduction efficiencies they can achieve. Vapor control systems are generally regarded as the most effective means of controlling highly volatile substances. The percent reductions achieved by an individual system is dependent upon design and operating parameters, e.g., cooling temperature or tank exhaust flow rate.

Condensers are suitable for any volatile substance. Most condensers utilize chilled water, at a temperature within the -5°C to 10°C range. The effectiveness of a condenser is directly proportional to the surface area of cooled tubes which contact the vapors to condense them. A typical condenser system is estimated to reduce emissions by 85 to 95 percent.[6]

Carbon adsorbers can be used for the control of volatile organic compounds. When large-scale adsorber systems are utilized (controlling a group of storage tanks), the system involves several units both in series and in parallel. The effectiveness of carbon adsorption systems is directly proportional to the length of time organic vapors are in contact with activated carbon. The individual-type "barrel" systems, which are more commonly used for the control of single storage tanks, are designed up with two or more units in series. The effectiveness of carbon adsorption has been estimated at a reduction efficiency range of 85 to 97 percent.[6]

Fume incinerators can be used to control any combustible (oxidizable) volatile substance. Generally the small systems wihch are employed for the control of an individual storage tank operate continuously. The effectiveness of vent incinerators is dependent upon the combustibility of the exhaust gas. Fume incinerators are estimated to be 85 to 99 percent efficient in reducing emissions.[6]

Costs

Vapor control systems are the most complete systems in use for control of storage tank emissions and, as a result, are the most expensive. The costs elements of such systems include design, construction, installation, material, storage, maintenance, energy, and labor. These costs depend primarily upon the design of tanks, number of tanks to be serviced, type of substances to be controlled, and materials handling considerations.

Condensers are more expensive than the small, individual storare tank carbon adsorption or fume incineration units, and are much less expensive than the larger carbon adsorption or vapor incineration systems. The cost of a condenser is dependent on the vapor flow rate, and the heat transfer surface area. Hall et al. estimated the costs of a variety of tank vent condensers to be between $2,000 and $19,000 (in March 1985 dollars).[17] The operating costs, including power consumption, maintenance, and service were estimated at approximately $10,000 annually.[6]

Carbon adsorption systems used to control storage tank emissions vary widely in cost between the large systems and the individual "barrel" type units. In general, large systems, which can cost up to $300,000 (in March 1985 dollars) to install and operate,[2] are not used to control TSDF storage vessels. Individual units are totally self-contained systems which can be easily installed as purchased. These systems have an expected lifetime of 6 months, depending upon the vapor exhaust flow rate. Many facilities use two or more in series and/or parallel to handle the exhaust capacity. Such a design scheme allows for continuous control if a particular unit needs to be replaced. The cost of such units was reported by a supplier at $670 and $920 per unit, depending on model type selected (the more expensive unit is capable of controlling hydrogen sulfide and acid gases).[16] Activated carbon suitable for adsorption of gas phase volatile compounds, may be purchased in bulk for approximately $1.00 to $1.50 per pound.[16]

Fume incinerators, similar to carbon adsorption systems, vary widely between the large-scale systems and the individual tank units. The large-scale systems may cost as much as $300,000 or more to install and operate (March 1985 dollars),[2] but are not commonly used at TSDFs for storage tank emission control. The cost of a small fume incinerator was estimated by MITRE at $7,500 to $11,000 per tank (March 1985 dollars).[6] Costs of such systems are highly dependent on vapor exhaust flow rate, ignition fuel usage, and combustion temperature.

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SECTION 5

CONTROL OF EMISSIONS FROM SURFACE IMPOUNDMENTS

INTRODUCTION

A surface impoundment is defined as "a facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials), which is designed to hold an accumulation of liquid wastes or wastes containing free liquids, and which is not an injection well."[1] There are three basic types of surface impoundments:[1] (1) totally excavated; (2) filled; and (3) combination. Excavated surface impoundments are constructed below grade-level; filled surface impoundments are built above grade; and combination surface impoundments are partially below grade. Most surface impoundments are combinations. Examples of surface impoundments are holding ponds, settling ponds, aeration pits, and lagoons. In general, surface impoundments are used for holding, storing, or treating large quantities of waste.

Surface impoundments have been estimated to be the largest source of emissions found at TSDFs.[3] Emissions occur predominently as a result of volatilization of substances from the surface. Particulate emissions may be produced as a result of wind erosion of dry substances which have formed around the impoundment perimeter. Gases may also be generated within a surface impoundment as a result of a chemical reaction, e.g., methane formation from decomposition of organics.

Emission control technologies applicable to surface impoundments may be classified as systems which either minimize the exposed surface area or reduce the affect of climatological forces such as wind, solar irradiation, or precipitation. The control options which are in use at surface impoundments may be categorized as follows:

- Covers;
- Aerodynamic modifications;
- Vapor control systems; and
- Operating practices.

Table 5-1 provides an overview of the advantages and disadvantages of the control options described in this section. Example systems will be cited, and the relative emission reduction effectiveness and cost of implementing these systems to existing TSDFs will be examined.

COVERS

Introduction

Covers placed over surface impoundments serve to limit emissions both by minimizing the available surface area and by insulating the impoundment constituents from wind and solar irradiation. Cover systems have been reported as the most widely applied technique of controlling emissions from surface impoundments.[4] There are a variety of cover designs in use at TSDFs, including:

- synthetic membrane covers;
- floating plastic spheres;
- rafts; and
- surfactant layers.

In general, cover systems are considered to be easy to install and relatively effective in emission reduction. System costs are dependent upon design and maintenance considerations. This section will present a detailed deescription of each of the above technology options.

TABLE 5-1. ADVANTAGES AND DISADVANTAGES OF SURFACE IMPOUNDMENT CONTROL ALTERNATIVES

Advantages	Disadvantages
COVERS:	
• Highly effective in reduction of surface impoundment emissions.	• Difficult to maintain.
• Controls both working and breathing loss emissions.	• May have poor weather resistance.
• Increase facility safety via liquid surface area minimization.	• May not be chemically compatible if waste constituents vary.
• May be applicable to amy size or shape impoundment.	• High materials costs.
• May be made from chemically inert materials and will not be reactive with waste.	• Gas and vapor permeability characteristics may be high.
• Nonrigid will not cause pressure buildup	• Direct-surface application may reduce thermal insulation.
• Removable.	• Entrapped vapors may cause pressure buildup and damage the cover system.
• Relatively low in installation and operating costs.	• Would require the addition of a vapor collection system to control releases.
AERODYNAMIC MODIFICATIONS:	
• Reduces emissions by reducing the effect of the wind creating turbulence on the liquid surface and sweeping vapors away from the impoundment to the atmosphere.	• Low emission reductions achievable.
	• Low strength and durability characteristics.
	• Has no effect on volatility impoundment constituents.

(continued)

TABLE 5-1 (continued)

Advantages	Disadvantages
AERODYNAMIC MODIFICATIONS: (Cont'd)	
● Facilitates recondensation of vapors at a surface impoundment.	● May require alteration of facility operating practices.
● Simple designs, which can be adapted to most impoundment sizes and shapes.	
● Easy to implement at an existing facility.	
● Little or no operating and maintenance requirments.	
● Low cost option.	
● Increases overall safety of facility.	
VAPOR CONTROL SYSTEMS:	
● Capable of achieving the highest emission reduction efficiencies of the control options described herein.	● Most costly of all control options. ● Highly complex systems to maintain.
● Completely remove vapor from cover system.	● Manpower required.
● Equally effective in reducing working and breathing losses.	● Materials required.

(continued)

TABLE 5-1 (continued)

Advantages	Disadvantages
VAPOR CONTROL SYSTEMS: (Cont'd)	
• Best available technology for highly volatile and/or toxic substances. • Basic design of systems are simple--they are easy to operate; and easy to design to fit a tank. • Can be applied to one or more than one impoundment. • Can be a single-pass or multiple-pass system. • Can selectively recover constituents. • Adaptable to a variety of wastes--can be used even if wastes stored changes. • Can regenerate carbon beds for continuous use. • Have found widespread usage at TSDFs.	• Space required. • Accessibility required. • Requires enclosed impoundment. • Requires equipment for the disposition of vapor control process products. • Subject to fire and explosion hazards. • Can be subject to design capacity limitations. • Performance is affected by prevailing weather weather conditions.
OPERATING PRACTICES:	
Increased Freeboard Depth	
• Applicable to any surface impoundment design.	• Emission reductions achievable are low.

(continued)

TABLE 5-1 (continued)

Advantages	Disadvantages
OPERATING PRACTICES: (Cont'd)	
Increased Freeboard Depth	
• Simple to implement at an existing facility. • Only costs involved are in construction of higher berms. No cost to lower level of liquid. Very low costs overall.	• May affect overall operation of facility due to lower impoundment capacity. • May be more applicable to smaller impoundment due to expected emissions reduction effectiveness.
Submerged Filling	
• Reduces emissions due to decreased turbulence of surface layer. • Applicable to most impoundments. • Particularly advantageous to impoundments which form a dry layer on top. • Low overall costs.	• Expense--may require construction and new equipment (piping, pumps). • Emission reduction efficiency is limited. • Waste characteristics may limit applicability. • Implementation may be difficult.
Less Frequent Drainage, Dredging, and Cleaning	
• Very simple to implement. • No costs involved (in fact, results in cost savings).	• May negatively affect the operation of the impoundment. • Emission reductions achievable are low.

(continued)

TABLE 5-1 (continued)

Advantages	Disadvantages
Less Frequent Drainage, Dredging, and Cleaning (Cont'd)	
	● May not be suited to all waste types, due to residence time requirements. ● Many facilities already conduct these procedures as infrequently as possible.

Description

Covers serve to limit emissions from surface impoundments by acting as an impermeable barrier. Waste constituents are thus held within an enclosed system. Covers are applied in such a way as to cover all or as much as possible of the available surface area. Cover systems may be placed directly upon the liquid surface (contact), on floats at the surface, or over the entire impoundment (noncontact). Covers may be made from a wide variety of synthetic materials, including elastomeric sheet, rigid foam, flexible foam, or liquid. In selecting an appropriate cover system, the following considerations determine the applicability of the system to a specific impoundment.:

- Type of waste impounded. The volatility, chemical reactiveness, density, and chemical compatibility with liner and cover materials.
- Design of the impoundment. The diameter, shape, depth, berm design, leachate collection mechanisms, and liner design.
- Inlet/outlet procedure. Whether the impoundment is filled and emptied from the top or from submerged pipeline.
- Impoundment status. Whether the impoundment is currently active or not, and the impoundment's primary function.
- Weather conditions. Wind, sun, and rain conditions which are prevalent.
- Manpower and materials. Maintenance and materials required.

The four cover systems which have found the most widespread use are described in detail below. Each system satisfies the above criteria to varying degrees. In general, however, they are applicable to most surface impoundments.

Synthetic Membrane Covers--

Covers made from flat sheets of synthetic material may be used to reduce volatilization from surface impoundments. These systems are analogous to floating blanket covers used to control storage tank emissions, which are described in Section 4. Synthetic membranes may be installed on surface impoundments so that they rest directly upon the liquid surface, or above the liquid, supported by floats or frames.[2] The cover may be constructed as one continuous sheet, or as interlockable sections. A wide variety of synthetic materials have been utilized as covers. Table 5-2 lists some of the more common cover materials.

The covers may or may not be anchored around the perimeter of the impoundment, they may be coated in some way, they may be exhausted to a vapor control system (see detailed description of vapor control, presented later in this subsection), and they may be colored to reflect sunlight. The primary considerations involved in selecting an appropriate membrane cover design for a surface impoundment are; chemical compatibility with waste constituents; resistance to weather conditions; gas and vapor permeability; tensile and tear strength; type of seams; anchoring technique;, and coloration.

One example of a cover system has been installed over an (425 ft x 150 ft x 8 ft deep) aerated lagoon owned by Upjohn, Inc. in New Haven, Connecticut. The air structure at Upjohn is a vinyl-coated, polyester membrane coated with Teflon on the inside. It is harnessed to the foundation around the impoundment by cables. Since installation, odor complaints have been decreased significantly.[1] This system is completely enclosed. Vapor which forms underneath the cover is exhausted to carbon adsorbers by two 75-hp aerators and 25 715-hp floating aerators. The carbon is regenerated by steam.

A similar structure without a vapor recovery system was installed over glauber salt storage ponds used by American Natural Gas in Beulah, N. Dakota, to keep precipitation out. The air structure, which is movable from one pond to another, covers approximately 2 acres and is made of vinyl-reinforced material over a concrete foundation. Two air blowers are used to keep the structure inflated. Another ground-mounted, air-supported structure was installed in Livingston, LA in September 1984.[1]

Floating Spheres--

A blanket of hollow plastic spheres may be used as a cover. These systems perform very much like synthetic membranes. However, plastic spheres are more fluid and are better thermal insulators. Gas and vapor permeability,

TABLE 5-2. SYNTHETIC COVER CHARACTERISTICS

Synthetic material	Chemical resistance	Weather resistance	Gas permeability resistance	Tear resistance
Chlorosulfonated polyethylene (Hypalon)	Inorganics--good Organics--poor	Excellent	Good	Poor
Polyethylene	Good for organics and inorganics	Poor	Excellent	Poor but better with thick (125 mil) sheets
Chlorinated polyethylene (CPE)	Inorganics and aliphatics-good Aromatic organics--poor	Excellent	Good	Cracks in cold weather
Polyvinyl chloride (PVC)	Inorganics--good Organics--poor	Poor	Good	Good
Polychloroprene (Neoprene)	Good for organics and inorganics	Excellent	Good	Excellent
Chlorinated polyethylene CSPE	Inorganics--good Organics--poor	Good	Good	Poor
Epichlorohydrin rubber (CO, ECO)	Good for organics and inorganics	Excellent	Good	Good
Ethylene propylene rubber (EPDM)	Inorganics--good Organics--poor	Excellent	Good	Good
Polyolefin	Inorganics--good Organics--poor	Excellent	Good	Good-but poor in cold weather

Source: MITRE, 1983 (Reference 2).

and weather resistance characteristics are not as attractive, however. Similar systems are used to control storage tank emissions. The reader should refer to Section 4 for further discussion.

Rafts--

A raft is defined as any device which floats freely upon the liquid surface. Rafts perform similarly to floating plastic spheres. Rafts have desirable gas and vapor permeability characteristics, may be designed to fit any size and shape impoundment, and are easy to install. Rafts have been used extensively to cover surface impoundments. Similar systems are used to control storage tank emissions. The reader should refer to Section 4 for further discussion.

Surfactant Layers--

A layer of liquid may also be used to cover a surface impoundment. In general, the surfactant layer is applied as thin as possible. Surfactant liquids generally employ long chain alcohols such as hexadecanol and octadecanol. The primary factor affecting the effectiveness of a surfactant layer cover is the maintenance of a continuous film on the liquid surface.[1] Similar systems have also been used to control emissions from storage tanks. Refer to Section 4 for further details.

Surfactant layers have been used to cover settling basins at three acrylonitrile manufacturing plants in Texas.[4] The settling basins are employed for suspended solids removal prior to deep-well injection of process wastewater. A layer of high-molecular weight lubricating oil, maintained at a thickness of approximately 0.1 m, is used to reduce the secondary VOC emissions. The lubrication oil is periodically replaced to make up for losses due to solubilization and evaporation.[4]

Emission Reduction Effectiveness

Surface impoundment cover systems are attractive for control of air emissions primarily due to the high emission control efficiencies which can be attained. The emission control effectiveness is dependent upon the type of compounds being held, the design (e.g., diameter, shape, depth) of the impoundment, and weather conditions.

The effectiveness of the four cover systems described in this subsection is directly proportional to the amount of surface area covered. A synthetic membrane is capable of covering the entire liquid surface area. Effectiveness of synthetic membrane covers is generally limited by the vapor permeability of the synthetic material and the perimeter seal. The efficiency of synthetic membrane covers was estimated by MITRE at 90 pecent.[2]

Rafts are capable of covering up to approximately 90 to 99 percent of liquid surface area depending on the raft shape relative to the impoundment shape. Effectiveness of rafts is also related to their thickness. Emission reduction efficiency of rafts was estimated in one recent study at 90 percent.[1]

Floating surfactant layers are capable of fully covering the liquid surface area. The effectiveness of such cover systems is primarily related to wind disruptions in the layers caused by wind. MITRE estimated that reduction efficiencies of 25 to 75 percent were achievable by such systems.[2]

Costs

The costs associated with a cover system on a surface impoundment are highly dependent upon cover design, the purpose of the impoundment, and operational considerations. The costs of covers include materials costs, installation costs, operating costs, and maintenance costs. Due to the large size of many surface impoundments, and the nature of the wastes they contain, some cover materials and installation costs are considered to be particularly high relative to other cover control options.

The costs associated with synthetic membrane covers are similar to those involved in similar systems implemented at landfills, which are discussed in detail in Section 6. Depending upon the synthetic material selected, the installed costs of the liner may range between $3 and $26 per square yard of impoundment area.[5] The cost of an air supported synthetic membrane system such as that at Upjohn was reported to cost over $500,000, while the installation cost of the American Natural Gas system was a reported $400,000.[1]

The cost of a layer of plastic spheres is similar for surface impoundments as that of the same technology applied to a storage tank. Refer to Section 4 for further detail.

The cost of floating raft covers are largely dependent on design considerations (e.g., raft thickness or coloration). Cost estimates for rafts applied fo surface impoundments must consider the usable life span. Rafts tend to become contaminated and must be occasionally replaced. The costs for a typical raft system was reported by Arthur D. Little to range between $0.05 and $0.13 per square foot.[1]

The costs of surfactant layers are potentially the lowest of any cover system. Materials costs are dependent upon the market price of the liquid used and, when these costs increase, other, cheaper liquids may be used. Installation and operating costs should be very low, and maintenance costs can be minimized by using the appropriate application procedure. The cost for applying a layer of hexadecanol, for example, is approximately 0.09 cents per square foot.[4]

AERODYNAMIC MODIFICATIONS

Introduction

The role of aerodynamic modifications is to alter, deflect, or eliminate the flow of wind across surface impoundments. Wind serves to cause or increase emissions from surface impoundments by sweeping VOCs or particles away from the surface impoundment to the environment. Aerodynamic modifications are used extensively for control of surface impoundments. The variety of designs currently in use may be classifed as either: barriers or shades.

Wind barriers and shades are considered to be, in general, easy to implement, and moderately effective at reducing emissions. Aerodynamic modifications are an attractive control option due to low costs. This section will present a detailed description of the above technology options.

Description

Aerodynamic modifications reduce emissions from surface impoundments by acting as a barrier or deflector to prevailing winds. Aerodynamic modifications are constructed to maximize reduction of wind across the surface impoundment. In general, the closer a barrier is to the impoundment, the more effective it will be in reducing winds. The higher the wind barrier, the larger its area of effectiveness. A wide variety of designs and materials of construction are employed in aerodynamic modification systems. In selecting the most effective aerodynamic modification system, the following considerations influence the applicability of the modification.

- Impoundment constituents. The volatility, reactiveness, and chemical compatibility (with barrier shades) of constituents.
- Design of the impoundment. The size, diameter, shape, depth, and berm design.
- Weather conditions. The sun, precipitation, and particularly the wind conditions.
- Maintenance and operating characteristics. The various maintenance and operating procedures employed at the facility (including need to access the impoundment).

Aerodynamic modifications have found widespread application for surface impoundment emission control, both alone and in conjunction with other control technologies. Barrier and shade systems, which are described in detail below, vary in their applicability under the above criteria depending upon design and operational constraints.

Wind Barriers--

A wind barrier is defined as any system which results in reduced wind flow across a surface impoundment. Various designs have been used at surface impoundments. These designs are similar to those which are used to control emissions in drum storage areas.

There are two basic types of wind barrier designs, perimeter and "compartmentalized." The barriers may be straight, or "zig-zag." Barriers may be oriented to face in one particular direction or may simply enclose the entire facility. Among compartmentalized designs, the internal cells may be uniform in size (e.g., the "honeycomb" design), or may be varied according to the use of the surface impoundment, maintenance, and constituents. Three examples of barrier designs, which have been tested in the field, and described by Crow and Monges,[1] are as follows:

- Open-picket baffles which consist of a picket-type snow fence supported by floats. The floats can be adjusted for different barrier heights, varying the ratio of the barrier spacing to the barrier height (L/H).
- Closed wind barriers which consist of a picket fence with flexible membrane linings fastened to the pickets.
- Styrofoam barriers consisting of Styrofoam strips joined to form a grid over the impoundment surface. No floats are necessary.

The primary considerations involved in selecting the most appropriate wind barrier design are the height of the barrier, compartmentalization, barrier materials (strength needed for prevailing winds, and compatibility with constituents), and impoundment access points.

Shades--

Shades are defined as systems which serve as wind-breakers and also reduce solar irradiation over the surface of an impoundment.[1] Unlike wind barriers, therefore, shades serve to limit both the effects of wind and sun, the two primary forces contributing to impoundment emissions. Various designs of shades have been developed for impoundments. Most involve a polypropylene mesh stretched over the surface of the impoundment.[1] In general, field testing has found that emission reduction effectiveness is proportional to mesh size. Shades may be made of a variety of colors, to either reflect or absorb radiant heat. They may also be coated with a chemical film to reduce vapor permeability. The primary considerations involved in selecting the most appropriate shade design are the mesh size, color, shade material (chemical compatibility), resistance to weather conditions (e.g., ability to handle a heavy snowfall), and shade anchoring. There are no application examples currently available.

Emission Reduction Effectiveness

The degree to which aerodynamic modifications are effective in reducing emissions from surface impoundments has been studied through field testing. The efficiencies that can be achieved are relatively moderate and, in some cases, low. When used in conjunction with other systems, however, the emission reductions that can be achieved are potentially attractive, considering their ease of implementation and low cost.

The reduction of wind speed by a wind barrier is dependent upon its height. The closer a wind barrier is to a certain point, the more effective it is in reducing wind. Barriers which are close together, however, tend to exacerbate emissions due to creation of a forced convection mechanism. That is, wind flow over the barrier walls creates a pressure differential within the enclosed cell, causing an upward flow of air which would increase emissions. Testing on windbarriers has shown that efficiencies range from as high as 80 percent to as low as 11 percent.[1]

The effectiveness of a shade is dependent on the shade value (see Table 5-3).[1] Chemical films tend to increase the effectiveness of shades due to decreasing vapor permeability. The efficiency of shade systems has been estimated by ADL to be 44 percent for nonaerated and floating immiscible layer impoundments.[1]

Costs

Aerodynamic modifications are considered to be among the lower cost control alternatives available for surface impoundments. The cost of such systems primarily consists of construction costs. Operation and maintenance costs are expected to be low under normal conditions.[1] The costs of installation are low relative to other control technologies, however, may vary as the aerodynamic modification system complexity increases. Weather conditions play a role in costs, as well. Damage due to extreme weather, such as a blizzard or hurricane, may result in high replacement and repair costs. The stronger the system is, the lower these costs may be. However, stronger systems also tend to be more expensive. In general, the costs have been estimated as follows:[1]

TABLE 5-3. EVAPORATION SUPPRESSION BY SHADES

Material tested	Evaporation reduction (percent)
Polypropylene Mesh 6 percent shade (natural)	26
Polypropylene Mesh 47 percent shade (black)	44

Source: ADL, 1984 (Reference 1).

- Barriers: $665/yr for styrofoam barriers formed in an 8 ft x 8 ft grid over a surface impoundment of median size (0.46 acres).
- Shades: $1663/yr for black woven polyethylene shades around a surface impoundment of median size.

VAPOR CONTROL SYSTEMS

Introduction

Vapor control systems control the release of volatile substances from surface impoundments by evacuating vapors which form and processing them physically or chemically. Vapor control systems are the most complex and costly of surface impoundment controls, but are the most effective at reducing emissions. Use of vapor control at surface impoundments is widespread.[1] The three vapor control systems which are most commonly used for surface impoundment emission control are:

- vapor condensation;
- Carbon adsorption; and
- Vapor incineration.

Of the three, carbon adsorption systems are probably the most frequently used. The three systems will be described in detail below.

Description

The primary function of a vapor control system is to remove vapors which form in a surface impoundment, and render them by physical or chemical process such that they will not enter the environment. Such systems are equally effective at controlling working or breathing losses, as any vapor which forms is evacuated from the impoundment. All vapor control systems involve at least three steps, as follows:

(1) evacuation;

(2) vapor processing; and

(3) recycle or venting of products.

The use of vapor control technology requires that the surface impoundment be enclosed. Therefore, only impoundments equipped with covers (see detailed description presented earlier in this section) will be able to utilize vapor control processes. Vapor control systems require the installation of ductwork, the location of unit processing equipment in readily serviceable areas, and equipment for the disposition of recovered products and materials. Vapor control systems have found widespread application at TSDFs, particularly in the control of highly volatile and/or toxic substances, due primarily to the high emission reduction efficiencies these systems can achieve. A vapor control system helps to alleviate a major drawback of surface impoundment covers. Covers tend to entrap vapors to the point where internal pressure builds up, and eventually causes damage to the system. Evacuation to vapor control eliminates this, while preventing these substances from entering the environment. The unit processes are themselves simple, utilizing the physical or chemical properties of surface impoundment constituents, such as vaporization point, adsorbability, or combustibility. In determining the applicability of a particular vapor control system to certain surface impoundment, the following factors should be considered.

- Properties of the surface impoundment constituents. The volatility, adsorbility on carbon or other substrates, and combustibility of waste constituents.
- Number of impoundments to be serviced. The total capacity to be served by a vapor control system.
- Manpower and materials requirements. The maintenance, operating labor, and materials required.
- Availability of space. The location of the vapor processing unit and attendant ductwork.

The three vapor control systems described below have found widespread application both in the control of surface impoundments and storage tanks, due not only to the high emission reduction efficiencies they can achieve, but also their applicability under the above criteria.

Vapor Condensers--

Vapor condensation systems prevent release of volatile substances by recondensing the vapors which form in an impoundment. These systems are identical to those used for control of storage tank emissions. Refer to Section 4 for further discussion.

Carbon Adsorbers--

Carbon adsorption systems prevent the release of volatile substances by adsorption of the volatile organic material onto activated carbon particles. The systems used to control surface impoundment emissions are identical to those used to control storage tank emissions. Refer to Section 4 for further discussion.

Vapor Incinerators--

Vapor incineration systems, also called afterburners, control surface impoundment emissions by oxidation (combustion) of volatile substances. The systems in use for surface impoundment emission control are identical to those used for storage tank emission control. Refer to Section 4 for further discussion.

Emission Reduction Effectiveness

Vapor control systems are highly effective at reducing emissions from surface impoundments. Efficiencies of these system were described in detail in Section 4. Refer back for further discussion.

Costs

Vapor control systems are highly complex, including much engineering design, materials, labor, operating costs, and maintenance. The control systems are, therefore, the most expensive of available control alternatives. Costs for such systems were described in Section 4. Surface impoundments may require additional installation and operating costs, due to their larger size requirement.

OPERATING PRACTICES

Introduction

The implementation of more effective operating practices at a surface impoundment serves to reduce emissions by limiting the affect of climatological forces (i.e., sunshine and wind) which contribute to emissions. Operations during the active life involving temperature of influent, dredging frequency, draining frequency, cleaning frequency, handling of sediments and sludge from dredging and types of wastes accepted at a facility could be designed to minimize emissions.[1] Many different operating practices have been instituted at TSDFs on the basis of reduced emission generation. To exemplify the type of measures which might be instituted at a surface impoundment, this subsection will focus upon three changes in operating practice, as follows:

- Increased freeboard depth;
- Inflow/outflow drainage pipe relocation to effect submerged filling; and
- Infrequent dredging, draining and cleaning.

While changes in operating practices are not considered to be more than moderately effective in reducing emissions (relative to add-on controls), they are often implemented at a TSDF on the basis of cost, ease of implementation, and simplicity.

Description

Changes in opeating practice at a surface impoundment could involve those which directly affect the waste material, the design of the surface impoundment, or external forces (such as sunshine, rain, and wind). These changes may involve new equipment, manpower training, or management. The following considerations should be made in determining the applicability of operating practice changes for a surface impoundment.

- Type of materials. The physical or chemical characteristics of impoundment constituents.
- Manpower requirements. Personnel and training requirements.
- Impoundment turnover. The rate at which a surface impoundment is filled and emptied and the retention time of waste material.

The three examples presented in this section, which are described in detail below, are commonly implemented at TSDFs due to their applicability under the above criteria.

Increased Freeboard Depth--

The freeboard depth is the distance from the top of the berm to the liquid surface. Increasing freeboard depth at a surface impoundment would serve to reduce air emissions by reducing the effect of wind and surface waves. This modification will decrease:

- volatilization;
- turbulence on the impoundment surface;
- spray formation; and
- erosion of dust and the dried surface of the impoundment.

There are two ways in which a facility can increase the freeboard depth of an impoundment: (1) decreasing liquid level, and/or (2) increasing berm height. Decreasing the liquid level of an impoundment would limit the capacity of the facility. For surface impoundments which operate at steady state (input rate = output rate, volume stays constant), a decrease in liquid level would also require changing (decreasing) the flow rate. Increasing the height of the berm would require additional material and construction. The draft RCRA Guideline Document (July 1982) suggest at least 60 cm (2 feet) of freeboard to prevent overtopping. A way to increase freeboard is to minimize runon into the impoundment by incorporating a runon control system.[1]

The primary considerations involved in selecting an appropriate freeboard depth for a surface impoundment are the capacity needed at the facility, the surface impoundment size, the requirements involved in construction of higher berms, and costs of berm material, labor, and more frequent draining of the impoundment. Increasing freeboard depth is applicable to any surface impoundment. Due to emission reduction effectiveness considerations, increasing freeboard depth as the sole means of control may be more applicable to small surface impoundments than to larger ones.

Inflow/Outflow Pipe Relocation--

By relocating the inflow and outflow pipes such that a surface impoundment can be filled and emptied from submerged points, emissions will be reduced due to reduced surface turbulence. Discharge of liquid on or above the surface on the impoundment not only causes the surface to become more turbulent but may also cause spray formation or degradation of any dry crust which may have formed over the impoundment. In designing a submerged filling system, it is advantageous to locate inflow pipes such that discharge occurs into the liquid bulk and below the surface. Relocation of pipes may require excavation for pipeline, new pipe, and new liner materials. The leachate collection systems may also require modification. Among the considerations involved in selecting a new inflow/outflow pipeline system are the size of pipe required, flow rate, pressure effects on filling and emptying, waste viscosity profile, excavation depth, and new materials requirements. New designs of surface impoundments primarily employ submerged filling and emptying. The frequency with which such systems are retrofit to existing surface impoundments is not known.

Less Frequent Dredging, Draining, and Cleaning--

By decreasing the frequency with which a surface impoundment is disturbed, emissions would be reduced due to decreased turbulence. Three ways in which this could be accomplished are through more infrequent dredging, draining, or cleaning of the impoundment. Such measures would require less labor and equipment, but might affect the impoundment process efficiency. The primary considerations involved in implementing such measures are the effect on the impoundment process (e.g., lowering the efficiency of settling), the waste materials, and the size of the impoundment (the smaller the impoundment, the less effective these measures would be). Such measures are quite attractive on the basis of decreased operating costs and, therefore, have been extensively used at TSDFs.[1]

Emission Reduction Effectiveness

There is no in-depth analysis present in the available literature which assesses the effectiveness of changes in operating practices in reducing emissions from surface impoundments. On the basis of engineering judgment, it is expected that such measures would be at most only moderately effective (in terms of emission reduction percentage). Increasing freeboard depth, for example, is analogous to construction of a perimeter wall of equal height. As described previously, wind screens have been found to achieve efficiencies of between 11 and 80 percent.

Costs

The costs involved in implementing changes in operating practice are generally low, in relation to other control alternatives. Costs are the primary factor in selecting such measures for TSDF surface impoundments.

The costs for increasing freeboard depth involve cost of berm materials, labor, and/or costs of more frequent drainage or lower capacity. Such costs are expected to be quite low, but are difficult to quantify. The more costly of the two methods described earlier would be increasing berm height due to materials costs.

The costs for changing to submerged filling and emptying are potentially the highest of the three operating changes described. Added costs would be incurred during implementation of the system, including new equipment, materials, construction labor, and maintenance labor. No information was available which quantified the total costs involved in such a change in operating practice.

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SECTION 6

LANDFILLS

INTRODUCTION

A landfill is defined as a waste disposal facility where wastes are placed in or on the land for custodial safekeeping.[1] Solid or semisolid wastes arrive in bulk or in containers, are placed in a landfill "cell" and are covered over with a soil layer of from 6 to 12 inches. A landfill is generally large in area, some extending several acres in size. Wastes in a landfill are isolated from the environment in the soil, and are left to degrade by chemical or biological process.

Atmospheric emissions from landfills can consist of both particulate matter and volatile organic compounds (VOCs). Air emissions can occur as a result of activities such as soil and waste handling, landfill maintenance, vapor diffusion, and/or wind entrainment. Diffusion may occur both vertically and laterally from the landfill cell. Emissions may also result from the leachate generated within a landfill and removed by a collection system.

There are two ways to control organic vapor emissions from landfills. One method is to place a barrier on the landfill surface to minimize diffusion into the atmosphere, thus, limiting the rate of volatilization. This type of control includes the use of a soil, foam, synthetic membrane cover, or encapsulation or solidification techniques. The other method is to collect the vapors and vent them to a treatment system such as a carbon adsorber or afterburner. This is the "ultimate" disposal method, because there is no chance for future volatilization of the compounds. This type of control includes gas collection.

An overview of the advantages and disadvantages of the control options described in this section is shown in Table 6-1. Also examined are the costs and efficiencies obtainable relative to vapor emission reduction.

SOIL COVERS

Introduction

Soil covers serve to limit emissions by acting as a barrier to diffusion and wind entrainment. Soil covers have experienced widespread use at municipal landfills, primarily for minimizing odors, reducing particulate emissions, and preventing rodent infestation. They have also been used to prevent leaching of hazardous chemicals to ground water due to infiltrating precipitation. A variety of soil covers have found usage as both a temporary and permanent cover, utilizing a wide range of soil types. Soil covers are considered to be relatively effective in preventing emissions and are very cost-effective.

Description

Temporary soil covers are placed over landfilled wastes as soon as is practical, usually at the end of each day. Soils suitable for use as temporary covers can sometimes be found nearby the landfill site; otherwise, they may have to be imported from offsite at added expense. Permanent soil covers usually consist of higher density soils, such as clay, which are less permeable to water percolation than are the soils usually used as temporary covers.

Layered covers may also be constructed using different materials (see Figure 6-1). These covers are placed over a landfill after all cells have been filled and the landfill is being closed. They may also be used in conjunction with a gas collection system. Often a layer of top-soil and vegetation is placed over a permanent soil cover to protect it against drying and physical damage.

The primary factor which controls the release of volatile organic chemical (VOC) emissions through soil covers is the air-filled porosity of the

TABLE 6-1. LANDFILL EMISSION TECHNOLOGIES--ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages
SOIL COVERS:	
• High volatile emissions reductions possibly depending on design operating practices and soil types used.	• Emissions may be significant depending on design, operating practices, and soil types used.
• Appropriate soils may be at or nearby landfill site.	• Ultimate release of all volatile constituents from landfill (unless gas collection used).
• Widely used technology.	• May crack or degrade due to natural processes over time.
• Can be used as a temporary or permanent control measure.	• Requires periodic maintenance (watering, inspection, etc.)
• Properly designed permanent soil covers serve dual purpose of minimizing infiltration and reducing volatile emissions.	
• Compatible with all waste types.	
• Can be used in conjunction with other technologies (e.g., synthetic membrane covers, gas collection).	
• Standard construction equipment used in implementation.	
• Moderate costs.	
SYNTHETIC MEMBRANE COVERS:	
• Very effective when used in conjunction with soil covers and/or gas collection.	• Emissions may be significant over a large area if not used in conjunction with other technologies.
• Virtually impermeable to infiltrating precipitation.	• Certain cover materials not compatible with some wastes.
• Available in many materials and thicknesses.	• May be punctured or torn easily, limiting use as a temporary cover.
• Widely used technoloyg.	• May crack or degrade due to natural processes over time.

(continued)

TABLE 6-1 (continued)

Advantages	Disadvantages
SYNTHETIC MEMBRANE COVERS: (Cont'd)	
• Most materials are moderate in cost.	• High performance materials may be very expensive (e.g., Teflon). • Requires periodic maintenance (inspection, watering, etc.)
FOAM COVERS:	
• May be used as a temporary cover. • May be useful for fugitive dust control. • Have been used at sanitary landfills in Europe. • Have been shown to be somewhat effective in mitigation of vapor release from spilled organic chemicals.	• Effectiveness questionable with respect to reducing emissions from hazardous waste landfills. • Some foams are incompatible with certain wastes. • Only effective as short-term control. • Long time necessary to apply an effective cover. • Application equipment and reagents costly.
ENCAPSULATION/SOLIDIFICATION:	
• Classification and encapsulation may be very effective. • Solidification has been used effectively for containment of radioactive wastes.	• High costs. • Some solidification agents are not compatible with organic wastes (e.g., thermoplastic solidification). • Encapsulation has not yet been developed on a commercial scale. • Solidification is not a proven technology for vapor emission control. • Not widely used technologies.
GAS COLLECTION:	
• Expected to be very effective when used in conjunction with a landfill cover system. • Has been used for methane gas migration control.	• Requires treatment system. • Some methods high in cost (e.g., trench vents). • Some gas barriers are not compatible with certain vapors.

(continued)

TABLE 6-1 (continued)

Advantages	Disadvantages
GAS COLLECTION: (Cont'd)	
● A simple, inexpensive system may be effective over a large area (e.g., single pipe vent with treatment). ● Can be constructed incrementally for use while landfill is still active. ● Easy, proven construction techniques. ● Moderate cost for most methods.	● Some gas barriers may be be ineffective in the control of vapors.
AIR-INFLATED STRUCTURES:	
● Expected to achieve high collection/removal efficiencies. ● Prevents infiltration as well as providing emission control. ● Synthetic membrane of soil covers would not be necessary if technology is adapted. ● Have been constructed over surface impoundments. ● Can cover areas as large as 5 to 6 acres.	● High costs. ● Requires treatment system. ● Structure may be somewhat permeable to vapors, depending on materials used. ● Have not been used over landfills. ● Probably not as cost effective as a cover with gas collection and treatment system.

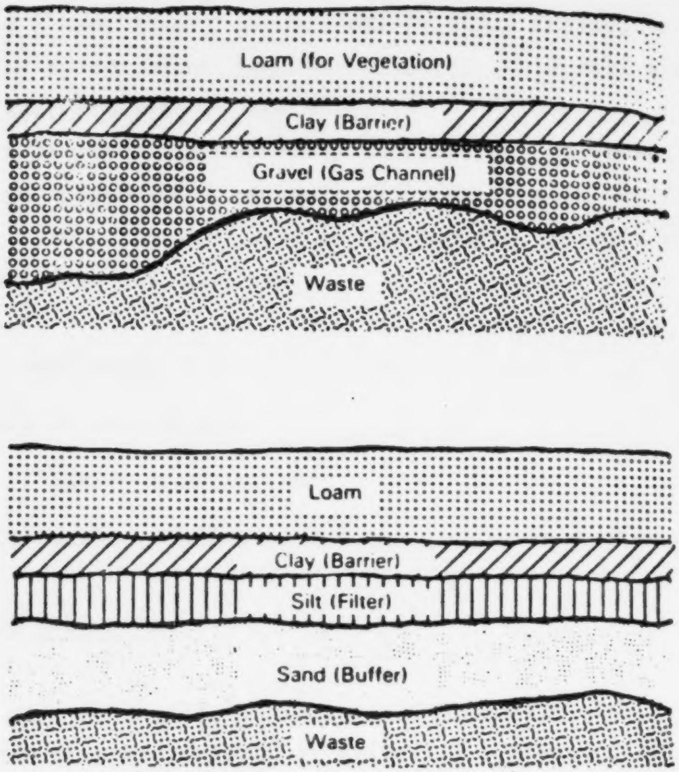

Loam (for Vegetation)
Clay (Barrier)
Gravel (Gas Channel)
Waste
Loam
Clay (Barrier)
Silt (Filter)
Sand (Buffer)
Waste

Figure 6-1. Two typical layered soil cover systems
(U.S. EPA, 1982) (Ref. 1)

soil.[2,3] Decreasing the air-filled porosity decreases the effective diffusivity of volatile materials through the soil. This can be achieved by using a denser cover material or by compacting existing materials. However, the most effective method of reducing air-filled porosity is to increase the moisture content of the soil. Maintaining the highest moisture content possible consistent with good workability and structural integrity of the soil will result in a significant decrease in emissions. This can be achieved by spraying temporary covers from a spray truck or other device, or installing a permanent sprinkler system after landfill closure. This will also prevent drying and subsequent cracking of the cover.

Emission release rates are inversely proportional to cover thickness. Hence, doubling the thickness of the soil layer will halve the release rate of VOC's through the cover. In selecting an appropriate landfill soil cover, the following considerations are important:

- type of soil used;
- thickness of soil layer;
- design of landfill cells; and
- landfill facility operating and maintenance practices.

Emission Reduction Efficiency

Soil covers are often used to control landfill emissions, due to the high emission reductions they are capable of effecting. Measured emission rates of hexachlorobenzene from an experimental landfill were reduced by 92 percent with the addition of a 1-inch soil cover.[3] A 40-inch soil layer was found to reduce emissions by 99.8 percent.

In the study mentioned above it was also found that decreasing soil water content by 2.3 percent increased hexachlorobenzene flux by 21.2 percent, clearly an exponential relationship.[2] A. D. Little[2] calculated theoretical emissions through 12-inch soil covers of different dry porosities and different moisture contents as shown in Table 6-2. It can be seen that increasing soil porosity increases the unit emission rate; increasing moisture content reduces emissions to virtually zero in the case of low porosity

TABLE 6-2. UNIT EMISSIONS THROUGH 12-INCH SOIL COVERS FOR SOILS OF DIFFERENT DRY POROSITY[a,b]

	Unit emission (ft/hr)			
	Dry porosity (bulk density)[d]			
% Water[c]	0.3(118)	0.4(101)	0.5(84)	0.6(67)
0	0.056	0.083	0.111	0.142
5	0.016	0.039	0.069	0.10
10	0.0020	0.015	0.039	0.073
15	0.0000032	0.0036	0.020	0.050
20	-	0.00033	0.0084	0.032
25	-	-	0.0027	0.020
% Moisture at zero porosity	15.8	24.7	37.1	55.8

[a] Units are $\frac{lb}{ft^2\text{-}hr} / \frac{lb}{ft^3}$ or ft/hr

[b] Diffusivity in air = 0.28 ft^2/hr; t = 1 ft.

[c] Percent of dry weight.

[d] Bulk density (lb/ft^3) in the parentheses, based on particle density = 2.7.

Source: Arthur D. Little, Inc., 1984. (Reference 2).

soils. It must be noted that these high levels of water content may not be achievable in practice. It is evident, however, that significant emission reductions are possible solely by increasing moisture content, probably on the order of 75 to 99 percent, depending on the soil type.

Other laboratory tests[2] indicate that changes in soil density on the order of 10 to 15 percent may be achievable in the field using heavy compacting machinery, depending on the type of soil. If the water content of the soil is about 15 lb/ft^3, this level of compacting can reduce effective diffusivity from 50 to 100 percent, resulting in similar reductions in emission rates.

Overall, it can be seen that both temporary and permanent soil covers are effective at reducing VOC emissions from landfills, particularly if they are maintained at a high moisture level.

Costs

The costs of soil cover systems used to control landfill emissions are low relative to other control alternatives, making such systems highly attractive. The costs of implementing such systems are largely dependent upon installation and maintenance requirements.

The costs for hauling, spreading, and compaction of a clay cover are about $11 per cubic yard of material.[1] The costs for hauling, spreading, and grading of top soil (sandy loam) are about $17 per cubic yard.[1] However, soils suitable for use as a temporary cover or for acting as a base for vegetation are usually found near the landfill site. Clays are usually not available nearby and hence must be trucked in from offsite.

The cost of hydroseeding grass over a landfill is about $1550 per acre of land.[4] Costs for irrigation systems or spray trucks have not been estimated, but their use is expected to be very cost-effective with respect to reducing air emissions. Other costs may be incurred for heavier earthmoving equipment for added compaction ability, or additional labor required to accommodate changes in operating procedures that reduce air emissions.

SYNTHETIC COVERS

Introduction

Synthetic covers perform similarly to soil covers in controlling landfill emissions. Placed on top of wastes, they serve to limit emissions by reducing vapor diffusion and acting as a barrier to the wind, sun, and any precipitation or runoff liquid. Synthetic covers have experienced widespread use at both municipal and hazardous waste landfills, where their main function has been the prevention of leachate generation. They are also effective in reducing atmospheric emissions of volatiles from landfills, especially if used in conjunction with a gas collection system and/or a soil cover. A wide variety of synthetic materials have found usage in this application. Their use with respect to emissions reduction will be discussed in this section.

Description

Synthetic membranes, commonly made of polymeric materials such as Hypalon, Neoprene, and elasticized polyolefin, can be used as temporary covers over landfill cells until the daily soil cover has been put into place. This practice will reduce atmospheric emissions to some degree. However, synthetic membranes are prone to puncture or tearing by landfilling equipment or other sharp objects, such as metal drums, and hence may have limited use as temporary covers.

As was mentioned earlier, synthetic membranes may be very useful as a permanent cover, especially if used in combination with a soil cover. A soil cover will not only further reduce emissions, but will protect the synthetic cover against drying and physical damage. Even when covered by soil, however, the synthetic cover may be subject to cracking or rupture.

It must be noted that certain organic vapors are incompatible with some liners. Compatibility of some organic vapors with Hypalon and Neoprene membranes is shown in Table 6-3. The primary considerations involved in selecting an appropriate synthetic cover for landfill emission control are:

- synthetic material and its compatibility with waste constituents; and
- membrane thickness and durability with respect to landfill operational and maintenance procedures.

Emission Reduction Effectiveness

Very little data exist on synthetic membrane permeability to volatile organic chemical vapors. However, available data suggest that, although synthetic membranes appear virtually impervious to water, they are somewhat permeable to organic vapors. The permeability of a given polymeric membrane to a given chemical depends on the solubility of chemical in the polymeric membrane because, unlike soils, synthetic membranes are nonporous.[5]

As can be seen from Table 6-4, which shows experimentally measured permeation rates through polymeric membranes for various organic solvent vapors, substantial variation occurs between compounds with different properties as well as between liner materials. Even a high-performance material such as Teflon does not appear to be effective against permeation of volatile chlorinated organics such as chloroform.

Costs

The costs associated with implementing a synthetic cover system are considered to be relatively low to moderate, depending upon the design of the system selected. The costs are primarily a function of material costs. In general, more favorable performance characteristics (e.g., low vapor permeability, high tensile and tear strength), result in higher material costs.

Unit costs of some installed synthetic membranes are presented in Table 6-5. These costs are only for the liner itself and do not include maintenance and inspection costs, or costs for soil covers.

TABLE 6-3. CHEMICAL RESISTANCE CHART (DUPONT)

Vapor type	Hypalon[a]	Neoprene[a]
Acetic acid (glacial)	X	C
Benzene	C	C
Butane	A	A
Butyraldehyde	X	C
Carbon tetrachloride	C	C
Cyclohexane	C	C
Dioctyl phthalate	C	C
Ethyl acetate	C	C
Ethyl alcohol	A (158°F)	A (158°F)
Formic acid	A	A
Gasoline	B	B
Hydrocyanic acid	B	A
Hydrogen sulfide	B	A
Kerosene	X	B
Methyl alcohol	A (158°F)	A (158°F)
Methylene chloride	C	C (100°F)
Methyl ethyl ketone	C	C
Naphtha	B	C
Perchloroethylene	X	C
Toluene	C	C
Trichloroethylene	C	C
Xylene	C	C

[a] Cured sheet.

A - Chemical has little or no effect.
B - Chemical has minor to moderate effect.
C - Chemical has severe effect.
X - No data - not likely to be compatible.

Unless otherwise noted, concentrations of aqueous solutions are saturated.
All ratings are at room temperature, unless specified.

Source: U.S. EPA, 1982. (Reference 1).

TABLE 6-4. PERMEATION RATES FOR ORGANIC CHEMICAL VAPORS THROUGH SYNTHETIC MEMBRANES

Membrane	Thickness (mills)	Vapor transmission ($g/m^2/day$)				
		Methanol	Acetone	Cyclohexane	Xylene	Chloroform
Elasticized polyolefin	22	2.10	8.62	760	359	3230
High-density polyethylene	30	0.16	0.56	11.7	21.6	54.8
Low-density polyethylene	30	0.74	2.83	161	116	570
Polybutylene	27	0.35	1.23	616	178	2120
Teflon	4	0.34	1.27	0.026	0.16	20.6

Source: Haxo et al., 1984. (Reference 5).

TABLE 6-5. ESTIMATED UNIT COSTS FOR SOME SYNTHETIC MEMBRANES

Membrane	Unit cost ($)
Hypalon (30-mil)	8.60/yd^2
Neoprene	6.60/yd^2
Ethylene propylene rubber	3.60 - 4.60/yd^2
Butyl rubber	9.60 - 5.00/yd^2
Teflon-coated fiberglass	26.50/yd^2
Elasticized polyolefin	3.60 - 4.80/yd^2
Chlorinated polyethylene	3.20 - 4.20/yd^2
PVC membrane (20-30-mil)	3.20 - 4.20/yd^2

Source: U.S. EPA, 1982 (Reference 1).

Total cost estimate data are limited. In general, they are considered to be somewhat greater than those for soil covers, but lower for most other control measures.

FOAM COVERS

Introduction

Foam covers are a relatively new technology which can be used in much the same manner as temporary soil covers. In terms of emission reduction, foam covers perform identically to soil and synthetic cover systems described previously. Foam covers have not been extensively utilized at hazardous waste landfills, but they have been used in Europe for several years in sanitary landfills as a substitute for a 6-inch soil cover. Use of foam covers in the past, has served to minimize particulate and gaseous emissions, rodent infestation, and disease-spreading organisms.

Description

Foam covers serve to limit emissions by acting as a barrier to vapor diffusion and wind entrainment of wastes, and reducing the affect of solar irradiation. In general, foams are used as a temporary cover system, applied over waste materials at the end of each day.

Foams used as landfill covers are liquid-based materials. A wide variety of foams may be applicable, depending on the waste characteristics and landfill design. Foam systems used are either mixed on-site or are "ready made" for immedite usage. Foams used to cover landfilled wastes are similar to those used to control spills from containerized waste. For detailed information on the materials, refer to Section 3.

Foam application is accomplished by either spraying or spreading material over the waste. Foam systems may be applied by manual or mechanical devices. Application equipment exists that can be operated by one worker. Larger systems which can be attached to a tractor can cover an acre in 1-1/2 hours.

Foam systems are a relatively new cover technology. The advantages to such systems are their ease and speed of application, their ability to control both particulate and VOC emissions, and their overall emission reduction effectiveness. Foam systems are only applicable as a temporary system, however, and thus necessitate daily costs. Foams may also be found to be incompatible with certain types of waste.

The primary considerations involved in selecting and determining whether a foam system is applicable for landfill coverage include:

- Type of foam. The chemical compatibillity with waste materials, mechanical (strength, durability) properties, and resistance to prevailing weather conditions.
- Application procedure. The equipment, design, and personnel required by a certain application procedure.
- Landfill status. Whether or not the landfill is active on a daily basis, preparing for closure, or in the process of commencing operations.

Emission Reduction Effectiveness

Foam covers are not a proven control technology for reducing VOC air releases. As mentioned earlier, their primary use has been at sanitary landfills. However, they may be effective at hazardous landfills as well. A study on the effectiveness of various foams in the mitigation of air releases from volatile chemical spills indicates that for nonpolar liquids, any high quality foam cover, regardless of its chemical type, will provide some degree of mitigation of vapor release.[8] Only alcohol foam was found to be stable against highly polar low molecular weight liquids such as acetone. The best foam agent in terms of vapor mitigation was the metal stearate-based alcohol type foam. Actual efficiencies for vapor emission control were not available, but it appears that most foams control vapors effectively for only 1 day or less. Longer-term control may be achieved with respect to fugitive dust releases.

Costs

Costs of foam cover systems are, in general, moderate to high relative to other comparable emission control alternatives. The costs are largely based on materials, equipment, and operating expenses. The cost of chemical reagents needed to generate a 2-inch layer of urea-methane complex foam is approximately 11 cents per square foot.[6] A one-man foam application system costs about $4,350. The high capital cost for equipment and reagents, the length of time required to apply the foam, and the temporary nature of foam covers indicate that foam covers may not be the most cost-effective of emission control options for vapor phase air release.

ENCAPSULATION/SOLIDIFICATION

Introduction

Encapsulation or solidification of wastes in a landfill serves to limit emissions by changing the physical properties of the waste itself. This process is considered to be effective for both vapor and particulate releases, particularly in limiting the affect of external forces, such as wind, on waste materials.

Solidification of wastes has been widely used, particularly in the transport and disposal of radioactive wastes. Solidification has not, however, been widely utilized at hazardous waste disposal sites, primarily because of cost[1]. Encapsulation techniques have only recently emerged from development and testing stages, and no large commercial-scale encapsulation facilities have yet been designed and operated.[1] The application of these technologies as vapor emission controls will be discussed in this section.

Description--

Waste solidification involves a number of techniques to seal wastes into a hard, stable mass. The basic process involves combining waste material with solidification agents. In theory, this would not only reduce the potential for organics to be leached into ground water by infiltration, but would also limit the evaporation of organics to the atmosphere. Six commonly used methods of solidification are cement-based, lime-based thermoplastics, organic polymers, self-cementation, and glassification.[1] Absorbent materials can also be used which reduce emissions by reducing the amount of exposed free liquid.[2] Mixing of solidification agents with waste should be carried out in closed vessels or enclosures which are vented to a carbon adsorber or other treatment system to minimize air releases to the atmosphere. Open mixing should be avoided if possible.[2]

Encapsulation is a process in which wastes are physically enclosed in a synthetic encasement. TRW Systems Group has developed bench-scale processes which are capable of encapsulating toxic and corrosive sludges and salts, as well as containerized wastes. This system requires the use of polybutadiene resin as an agglomeration agent and high-density polyethylene for an encapsulation jacket. (See Figure 6-2). As was mentioned earlier, commercial encapsulation facilities are not yet in operation at landfills. For a more detailed discussion of encapsulation processes used to control emissions from containerized waste, see Section 3.

The considerations which are involved in selecting an encapsulation or waste solidification (e/ws) technology appropriate to a particular landfill facility include:

- Waste characteristics. The volatility, density, corrosivity, and diffusivity of waste materials to be encapsulated or solidified.
- Operational and equipment requirements. The need for specially trained personnel, procedures, and equipment required by a certain e/ws technology.
- Availability of materials. Whether or not the required materials will be available, transportable, and interchangeable.
- Landfill status. Whether or not a landfill is active or inactive.

Emission Reduction Efficiency

No data are available in the literature on the fate of volatile organics in solidified or encapsulated wastes. Some solidification agents are not

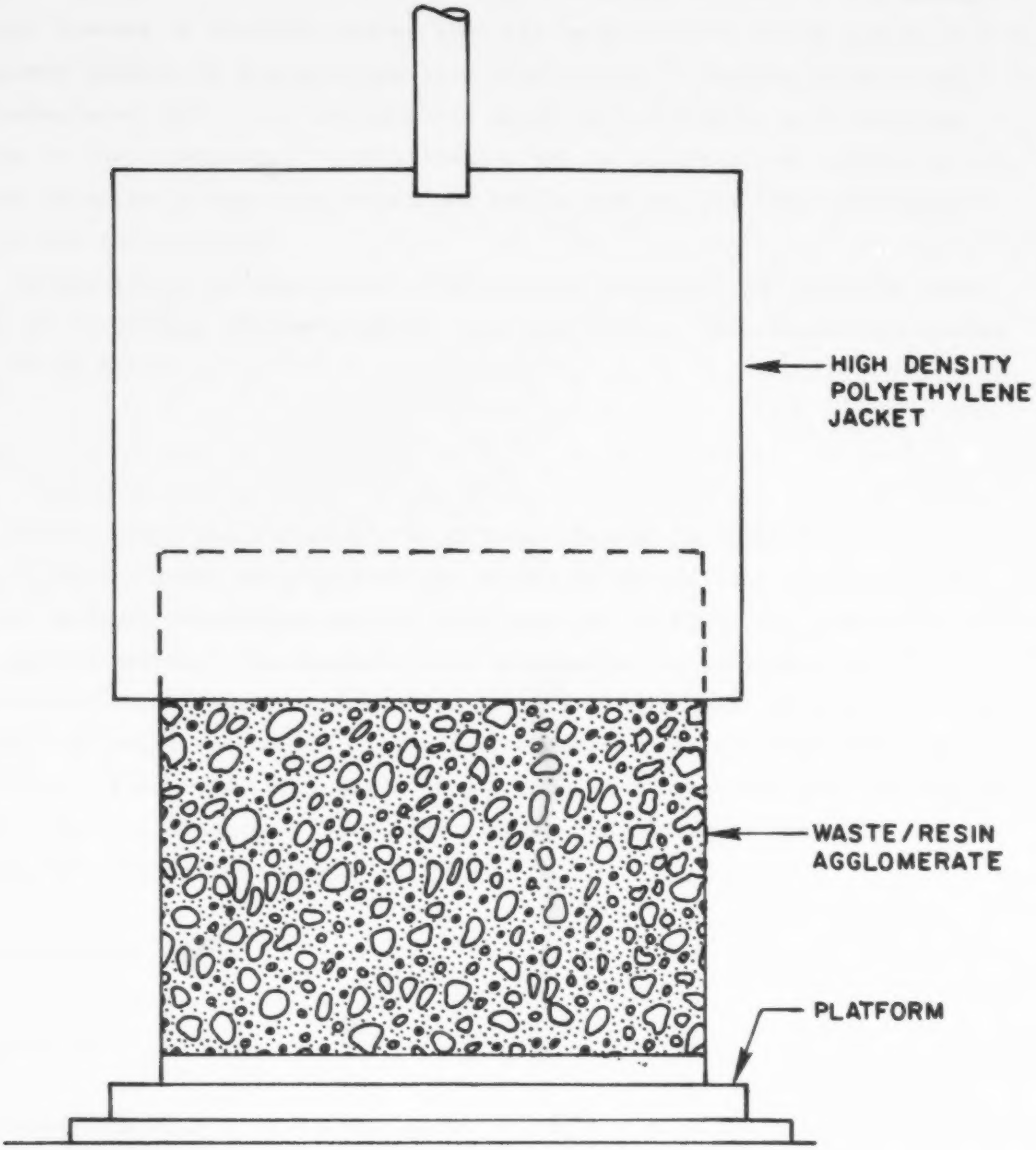

HIGH DENSITY POLYETHYLENE JACKET
WASTE/RESIN AGGLOMERATE
PLATFORM

Figure 6-2. Encapsulation process concept.
(Source: U.S. EPA, 1982) (Ref. 1).

compatible with organic wastes, and hence may not be applicable. These include lime-based thermoplastics and self-cementing methods.[1] The maximum organic content of chemical wastes that can be solidified using cement is 2 to 3 percent because of process chemistry limitations.[6] Organic polymers may be biodegraded over time, losing their structural integrity and releasing vapors to the atmosphere. Glassification may be an effective solidification method relative to emission reduction, but it has not yet been adequately tested for this purpose.

Encapsulation is considered to have great potential in isolating many types of waste from the environment, but also has not been adequately tested on a large scale.

Costs

Cement costs range from $77 to $106 per ton at the mill.[1] Solidification costs will vary widely depending on the site and waste types. Organic polymer solidification has been reported at $3.60 per gallon for radioactive wastes.[1] No specific cost information is available for glassification, but it is expected to be very high because of its intensive energy use, requirements for highly trained personnel, and sophisticated machinery. Projected costs for encapsulation at a plant are $120 per ton of waste. This estimate will vary depending on the nature of the waste and the encapsulation materials used.[1]

GAS COLLECTION

Introduction

Systems designed to collect gases which form at a landfill serve to limit emissions by reducing the amount of volatile materials entering the atmosphere. Gas collection systems are intended to divert vapors to control systems such as a carbon adsorbers or afterburners. These technologies were discussed previously for surface impoundments and storage tanks, and are detailed in Section 4.

Gas collection has been used primarily for controlling methane gas generated in sanitary landfills, but has also experienced some use for control of volatile toxics as well.

In general, such technologies are considered to be highly effective. The costs to implement such systems, however, may be high.

Description

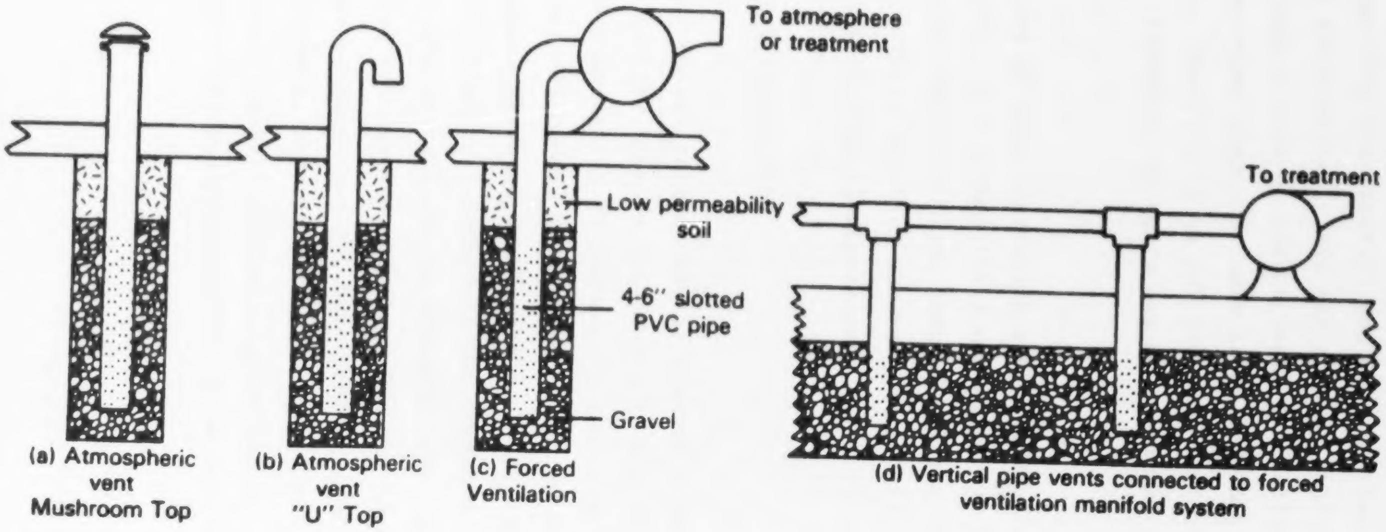
In their simplest form, a gas collection system may consist of a single pipe vent connected to a small fan, discharging to a treatment device. Since the radius of influence of a single forced ventilation pipe has been found to be as high as 200 to 300 feet, it is conceivable that a simple fan and vent system could be used for landfills as large as 5 to 6 acres.[1] Several technologies are available for use in gas collection, including pipe vents, trench vents, and gas barriers. These technologies are discussed below.

Pipe Vents--

Pipe vents consist of vertical or lateral perforated pipe installed in a landfill either incrementally, as the landfill is still in operation, or as part of landfill closure. They may be installed within or around the landfill, and in combination with trench vents for lateral migration control. The pipe vents are usually surrounded by a layer of coarse gravel or sand to prevent clogging, as shown in Figure 6-3. Several pipe vents will connect to an exhaust header which may, in turn, be one of several header branches leading to a larger manifold blower. Each branch may have butterfly valves for balancing and flowmeters for checking flow rate. Such complicated systems are usually applicable only to landfills larger than 5 or 6 acres.

Trench Vents--

Trench vents are constructed by excavating a deep, narrow trench surrounding a disposal site or spanning a section of the area perimeter. The trench is backfilled with gravel, forming a path of least resistance through which gases can pass. Trench vents are often used in conjunction with liners to form an effective barrier against gas migration. To prevent organic vapor emissions, the trenches are capped with clay or a synthetic membrane and


To atmosphere
or treatment
Low permeability
soil
4-6" slotted
PVC pipe
Gravel
To treatment

(a) Atmospheric vent Mushroom Top

(b) Atmospheric vent "U" Top

(c) Forced Ventilation

(d) Vertical pipe vents connected to forced ventilation manifold system

Figure 6-3. Pipe and trench vents (U.S. EPA, 1982) (Ref. 1).

fitted with collection pipes. These are connected to a negative pressure fan which removes vapor from the landfill and directs them to a gas treatment system such as an afterburner.[4] Air can also be injected on one side of a disposal area through a pipe or trench vent, and collected through a pipe or trench vent on the other side. In some cases this may be the most effective collection method. However, it is not desirable to exert net positive pressure within a landfill, as seals may be ruptured, and vapors released.

Gas Barriers--

Barriers to gas or vapor migration can be employed in a number of ways at waste disposal sites. Low permeability materials suitable for constructing gas barriers include compacted clay, concrete slurry walls, gunite, and synthetic liners.[1] These barriers can be used to direct vapors or gases to trench vents or prevent lateral migration outside of the landfill area.

Emission Reduction Effectiveness

The efficiency of gas collection and treatment systems depends primarily on the collection system, because the treatment portion can usually achieve levels of efficiency exceeding 95 percent.[2] One study[9] has estimated that landfill gas control efficiency is between 70 and 90 percent. Trench vents attached to a negative pressure fan or blower by collection pipes offers the most effective lateral control method if the trenches extend to ground water or bedrock. Pipe vent systems may be somewhat less effective but may be less expensive and useful at a greater depth.[2] The use of gas barriers to control lateral gas movement has not been tested. The discussion on synthetic and clay liners, however, indicates that they will not be extremely effective as they are somewhat permeable to some organic vapors. The integrity of concrete slurry walls and gunite barriers may be difficult to achieve and maintain.

Costs

Costs associated with gas collection systems are considered to be high relative to other control alternatives, due to the complexity of the systems involved. The costs are based primarily on equipment costs and installation costs. The cost of installed vent pipe range from $2.60 to $3.30 per inch (diameter) per foot (depth) for small diameter pipes. This excludes casing costs. Casing costs are $6.00 and $8.60 per foot for 4-inch and 6-inch casings, respectively. In addition, the cost for a fan capable of producing 3 inches of static head and a flow rate of up to 3 cfm would be approximately $800. Therefore, the total installed cost of a single forced ventilation pipe vent, 4 inches in diameter and 30 ft deep would be approximately $1450. This does not include treatment of the collected vapors.

The cost associated with trench vent installation includes the excavation cost in addition to costs for the gravel fill, the lateral and rise pipe, and liner material. Excavation accounts for 80 percent of the total cost. The total installed cost of a trench vent 20 ft deep, 4 ft wide, and 500 ft long (1500 yd^3) using a hypalon liner would be approximately $330,000.[1]

AIR-INFLATED STRUCTURES

Introduction

An air-inflated structure is a system which completely covers a landfill. Emissions are effectively reduced by such systems because they act not only as a synthetic membrane cover, but as a gas collection system as well.

Air-inflated structures have been used to some degree for reducing emissions from or keeping precipitation out of surface impoundments. The principle behind air-inflated structures could be easily applied to landfills. No information was found describing their use over landfills.

Description

An air-inflated structure consists of a large synthetic membrane, sealed around the edges, and filled with air for support. Usually large fans or blowers introduce air into the structure, and the structure is vented to a carbon adsorber, afterburner, or other gas treatment system. Thus, emissions from a landfill would be collected and treated before they could reach the atmosphere. Air locks for vehicle entrance and exit can be installed, allowing emission-free entrance. Air-inflated structures could be used to cover landfills ranging in size from a fraction of an acre to 5 or 6 acres. Section 4 of this report provides a discussion of this vapor collection/treatment system.

The use of air-inflated structures to cover landfills has not been documented. This type of air emission control technology has, however, been utilized to control emissions from surface impoundments. Two applications, one at the UpJohn chemical company in New Haven, CT, and another at American National Gas, in Beulah, ND, have been discussed previously in Section 5 of this document.

The primary considerations involved in selecting and determining the applicability of a suitable air-inflated structure design for a particular landfill include:

- Synthetic membrane materials. The materials chemical compatibility with waste materials, tensile and tear strength, and resistance to weather conditions.
- Landfill design. The size, shape, and cell design of a particular landfill.
- Landfill operational and maintenance characteristics. The frequency of access and egress, usage patterns, and maintenance requirements of a landfill.
- Support system. The costs, maintenance, location, and energy requirements of the air support system.

Emission Reduction Effectiveness

The efficiency of an air-inflated structure is dependent primarily on the vapor permeability of the membrane and the air-tightness of the structure. Relatively impermeable, well-sealed structures vented to gas treatment systems are generally 95 percent efficient, or more. As mentioned previously with regard to synthetic covers, emissions through synthetic membranes may be substantial. However, the use of a high-performance cover, such as the

Teflon-lined membrane used at the Upjohn facility will serve well to reduce emissions.

Costs

The cost of the Upjohn structure was about $400,000, including installation. In addition, carbon adsorbers, fans, and other expenses totalled about $100,000. The American Natural Gas structure also cost approximately $400,000, installed. Costs of this control option will vary depending on the materials used and the size of the landfill. Estimated costs for two sizes of air-inflated structures are presented in Table 6-6. The two sizes represent the approximate range of landfill sizes over which an air-inflated structure can be built. Based on these estimates, costs will range from $6 to $9 per square foot of floor space.

Despite their high cost, air structures may be applicable in certain situations. If an air-inflated structure were installed over a large landfill, there would be no need for soil or synthetic covers or other gas collection systems. Precipitation would be kept out, and volatiles would be effectively collected and removed.

TABLE 6-6. CAPITAL COSTS FOR AIR-INFLATED STRUCTURES[a]

	17,000 ft^2	260,000 ft^2
Structure	70,000	985,000
Heating	24,500	175,000
Lighting	15,000	Not estimated
Vehicle air lock	15,000 - 24,000	Not estimated
Installation	25,500	390,000
Total	150,000	1,600,000
Annualized (10%, 10 years)	24,000	250,000

Source: A. D. Little, 1984 (Reference 2).

[a] Treatment system costs not included.

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SECTION 7

CONTROL OF AIR EMISSIONS FROM LAND TREATMENT FACILITIES

INTRODUCTION

Land treatment is a method of destroying wastes by applying them to a plot of land and allowing soil microbes to biodegrade them. Because the waste is often tilled to enhance biodegradation, significant volatilization of organics may also occur. The technologies in this section describe methods which reduce vapor emissions by:

- providing a barrier against free diffusion (covers);
- changing operating practices including subsurface injection, decreasing application rate, and increasing soil moisture content; and
- collecting and treating the vapors generated (air-inflated structures).

Table 7-1 presents an overview of the advantages and disadvantages of the land treatment facility control technologies described in this section. Costs and efficiencies of these technologies will also be examined in detail.

CHANGES IN OPERATING PRACTICES

Introduction

Since volatilization of organic compounds in soil is greatly influenced by such practices as tilling, changing certain operating practices can significantly reduce emissions from land treatment areas. Changes in

TABLE 7-1. LAND TREATMENT EMISSION CONTROL TECHNOLOGIES--ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages
OPERATIONAL PRACTICES	
• Subsurface injection is expected to achieve significant emission reductions for some wastes. • A subsurface injection tool bar can be fitted onto an existing waste application vehicle at nominal cost. • Maintaining a high soil moisture content will reduce emissions significantly. • Reducing waste application rates may increase biodegradation rates, resulting in a decrease in emissions.	• Subsurface injection may not be effective for highly volatile compounds. • High initial cost for a complete subsurface injection vehicle. • Increasing injection depth may decrease biodegradation rates, resulting in an increase in emissions. • Reducing application rates may not be economically justifiable, given the small emissions reductions possible.
COVERS	
• May serve as effective temporary measures to reduce emissions from land treatment areas, especially if the wastes being treated are highly volatile.	• Soil covers increase the volume of material present in the land treatment area, limiting the volume of waste that may be applied. • Synthetic membranes can be easily torn or punctured, limiting their effectiveness as temporary covers. • Foam covers are not compatible with certain wastes.

(continued)

TABLE 7-1 (continued)

Advantages	Disadvantages
COVERS (continued):	• Foam covers may be too expensive for temporary use. • Covers may decrease biodegradation rates, resulting in an increase in emissions.
AIR-INFLATED STRUCTURES	
• Expected to achieve high collection/removal efficiencies. • May be necessary for land treatment areas receiving highly volatile wastes or located in densely populated areas. • If adopted biodegradation rates could be maximized without heed to odor generation or volatilization. • Have been constructed over surface impoundments. • Can cover areas as large as 5 to 6 acres. • If a carbon adsorption system is used, condensate from steam regeneration of the carbon may be returned to the land treatment area to be further biodegraded.	• High cost. • Requires treatment system. • May be somewhat permeable to vapors, depending on materials used. • Have not been used over land treatment areas.

operating practices involve both the purchase and installation of new equipment or facilities, and/or the alteration of waste treatment and handling methods employed at the facility. One change that can be made is to inject wastes below the land surface, as opposed to applying them on the soil surface and tilling them into the soil. Other changes include decreasing the waste application rate and maintaining a high soil moisture content.

Description

Subsurface Injection--

Subsurface injection is a method of applying wastes below, as opposed to on the land surface. This minimizes waste contact with the atmosphere, resulting in reduced emission rates. Basic subsurface injection equipment consists of a tool bar attached to the rear of a truck or tractor with two or more chisels, similar to a chisel tooth plow, attached. Adjustable sweeps are often mounted on or near the bottom of the chisels to open a wide but shallow cavity underground. A tube connected to the waste source leads down the back of the chisel, and, as the sweeps open a cavity, the waste is injected. With proper adjustment and use, very little waste reaches the soil surface.[1] Using this method, waste is usually injected 4 to 8 inches below the land surface. In other devices, waste is simultaneously injected below land surface and mixed into the top 6 to 10 inches of soil. The initial injection may be followed closely by a second pass with a cultivator to distribute waste uniformly throughout the treatment area.[2] In all cases, waste should be injected to the maximum depth consistent with maintaining high biodegradation rates. If biodegradation rates are decreased significantly by deep injection, waste will remain in the soil for longer periods of time.

Subsurface injection was originally developed by the agricultural industry and is commonly used for applying anhydrous ammonia and liquid manures.[1] Subsurface injection is recommended for any biodegradable wastes with volatile and/or odorous constituents, such as wastes generated in the petroleum and chemical manufacturing industries.

Decreased Application Rate--

Emission rates are affected by the waste application rate per unit area.[2] In theory, waste should be applied at the maximum rate compatible with the degradative capabilities of the land treatment soil/microbe system. In practice, however, land treatment areas are generally overloaded with waste, resulting in decreased biodegradation rates, and subsequently increased emission rates due to increased residence time of wastes in the soil. Nominal application rates range from about 22 to 66 metric tons per hectare.[1]

Moisture Control--

As discussed earlier under the section on landfill soil covers (see Section 6 for further details), effective diffusivity of organic vapors can be increased dramatically with only small decreases in soil moisture content. Maintaining soil moisture at the highest levels consistent with good biodegradation rates and soil workability will serve to greatly reduce emissions.[2] This can be achieved by using spray trucks or by installation of an irrigation system.

Emission Reduction Effectiveness

Table 7-2 shows theoretical annual losses from a 1-acre land treatment area based on emission equations discussed by A. D. Little (1984).[2] Although the equations do not include the effects of biodegradation, the data are useful for comparing surface application versus subsurface injection. Actual emissions would probably be lower in both cases by varying amounts due to biodegradation. The data indicate that for compounds of low volatility (vapor concentrations below approximately 1000 ppm), subsurface injection reduces emissions by more than 90 percent as compared to surface application followed by plowing under. For higher volatility compounds, efficiency may be less than 60 percent.

TABLE 7-2. ANNUAL EMISSIONS FROM A THEORETICAL 1 ACRE LAND TREATMENT AREA[a]

	Surface application followed by tilling		Subsurface injection		Percent reduction	
Depth of injection Depth of plow slice	0 4"	0 8"	4" 4"	8" 8"	4" 4"	8" 8"
Equilibrium Vapor Pressure (ppm by volume)						
10	4.8	3.4	0.1	0.05	98%	99%
50	10.7	7.6	0.2	0.1	98	99
100	15.2	10.7	0.4	0.2	97	98
500	34	24	2	1	94	96
1,000	48	34	4	2	92	94
5,000	107	76	20	10	81	87
10,000	152	107	40	20	74	81
50,000	287[b]	246	200	100	< 59	59
100,000	287[b]	287[b]	287[b]	200	<< 59	< 59

[a] Units are in metric tons per year; 287 metric tons of waste applied per year.

[b] Complete (100%) loss.

Source: A. D. Little, Inc., 1984. (Reference 2).

The emissions reductions associated with reducing the application rate of wastes will depend on factors such as soil type and waste types applied, but overall will be relatively small as compared to reductions from using subsurface injection.

Emissions reductions achievable by maintaining a high soil water content have been described under the section on landfill soil covers (Section 6). In general, a small increase in water content results in a substantial decrease in emissions from soils due to the decrease in the soil's air-filled porosity.

Costs

The cost of a subsurface injection vehicle will range from $98,000 to $158,000, depending on the vehicle's waste storage capacity, engine size, and the addition of optional equipment.[3] However, a subsurface injection tool bar fitted onto an existing waste application vehicle costs between $5,400 and $8,700.[3]

Decreasing the application rate may involve substantial costs, as more land would be required to treat a given quantity of waste. If more land was not available, costs would be incurred in the form of alternative offsite treatment methods.

Maintaining a high soil moisture content may involve initial capital costs for spray trucks or irrigation systems, but operating costs will be very low.

Overall, it appears that both subsurface injection and maintaining a high soil moisture content are very cost-effective methods for emission reduction. Higher efficiencies can be obtained, particularly for highly volatile wastes, or at land treatment areas in congested locations by installing systems such as air-inflated structures with vapor collection/treatment devices. However, costs can be substantially higher. (See Section 4 for a discussion of vapor collection/treatment systems).

COVERS

Introduction

Covers similar to those employed at landfill facilities (see Section 6) may be used as a land treatment facility emission control device. A cover acts as a physical barrier to both external forces such as wind, soil, and vapor diffusion from the soil matrix. The various covers which may be used at a land treatment facility are the same as those used at a landfill, namely:

- soil;
- synthetic membrane; and
- foam covers.

There is little evidence that covers have been used at land treatment. However, covers are considered to be a potentially effective, relatively low cost control option.

Description

Any material or system which can be applied over land treatment facility which acts as a physical barrier to vapor diffusion, and to external forces such as solar irradiation, wind, and precipitation is called a cover. Land treatment covers are made from solid or semisolid (foam) materials, applied as continuously as possible over the surface area. In general, application procedures require a truck or tractor due to the size of the facility. Depending on the system employed, land treatment covers are sprayed, sifted, or spread over the soil/waste complex. Covers may be used as a temporary emission control measure on active land treatment, but are perhaps more applicable to inactive facilities. In general, the selection and determination of the most appropriate cover system to be implemented at a land-treatment facility must consider the following important factors:

- Design of land treatment facility. The size, shape, slope, and vehicular negotiability of a land treatment facility.

- Type of waste materials. The vapor diffusivity, chemical compatibility with cover materials, biodegradation characteristics, and application requirements of the waste materials.
- Design of cover systems. The application procedure, materials handling requirements, strength, weather resistance, durability, and vapor permeability.
- Operating procedures. The personnel requirements, waste handling methods, and activity of a particular facility.

Further detail on the three cover systems is provided in Section 6 of this document on landfill emission control technologies.

Emission Reduction Effectiveness

The efficiency of covers in reducing emissions was discussed in detail in the landfill section (Section 6). Synthetic membranes may be easily torn or punctured in the field, and may be awkward to put into place. Foam covers may not be effective for certain types of waste. Soil covers would increase the volume of material in the land treatment area, limiting the volume of waste that could be applied. In all cases, covers will provide a barrier to free diffusion, but because they are not part of a collection and treatment system, diffusion will continue at a reduced rate. Also, covers may affect the biodegradation rate of wastes in the land treatment area by changing factors such as oxygen content and/or temperature. Such changes may ultimately result in greater emissions.

Costs

Costs for soil, synthetic, and foam covers have been discussed in the landfill section of this report (Section 6). Overall, it appears that changes in operating practices will be more cost-effective than covers. If, however, the waste in question is of high volatility, and subsurface injection cannot offer sufficient control, covers may be a viable option for temporary emission control.

AIR-INFLATED STRUCTURES

Introduction

The use of air-inflated structures at land treatment facilities has not been documented in the literature. Such structures have been used for reducing air emissions from surface impoundments, as discussed in Section 5. It is conceivable that air-inflated structures would be equally, if not more applicable to land treatment areas, due to the higher potential for significant air releases.

Description

Air-inflated structures consist of a synthetic membrane structure supported by air pressure and attached with cables or by other means to a foundation. Fans force air into the structure which is then vented to a treatment system to remove organic vapors. Used over a land treatment area, biodegradation rates could be maximized without regard to volatilization from the soil (e.g., by using surface application). Organic vapors emitted from the soils would be captured by the structure and treated. If a carbon adsorption system is used, condensate from steam regeneration of the carbon may be returned to the land treatment area for further treatment. Air structures can be constructed over land treatment operations ranging in size from a fraction of an acre to 5 or 6 acres.[2]

Emission Reduction Effectiveness

As mentioned in Section 6, the efficiency of air-inflated structures is dependent on the permeability of the membrane and air-tightness of the structure, as treatment technologies can effect greater than 95 percent removal. Emissions through membranes can be significant over a large area. However, since the vapor concentration within the structure is expected to be lower than that under experimental conditions, it is expected that emissions through the membrane will be minimal, hence, air-inflated structures are expected to achieve better emission reduction rates for higher volatility compounds than subsurface injection. For low-volatility compounds, the efficiency is expected to be about the same, or less.

Costs

Costs for air-inflated structures have been presented in the landfill section (refer to Table 6-6 in Section 6). Air-inflated structures may be more cost effective for land treatment areas than for landfills because of the potential for greater emissions from land treatment. The use of air-inflated structures is an option to be considered for land treatment areas in densely populated zones and/or if highly volatile or odorous constituents are being treated.

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SECTION 8

CONTROL OF AIR EMISSIONS FROM WASTE PILES

INTRODUCTION

Waste piles are a common method of storing solid wastes. Storage in a waste pile is particularly applicable to fine-grained waste materials, such as ash, sand, or contaminated sorbent. Some of the waste material kept in piles at TSDFs may contain volatile organic compounds. Because of the physical nature of these wastes, they may be subject to erosion by wind, resulting in fugitive dust emissions, or volatilization of any organic materials present in the wastes. A variety of methods are described in this section which control fugitive dust emissions and/or vapor emissions from waste piles, including:

- enclosure (covers);
- stabilization (physical, chemical, vegetative, or wet dust suppression);
- vapor collection and destruction (gas extraction);
- windscreens; and
- changes in operating practices.

Table 8-1 provides an overview of the advantages and disadvantages of waste pile emissions control technologies described in this section. These methods will also be examined in detail in terms of cost and emission reductions effectiveness.

TABLE 8-1. WASTE PILE EMISSION CONTROL TECHNOLOGIES--ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages
STABILIZATION	
• Chemical stabilization may be very effective for extended periods of time. • A wide variety of chemical stabilizers are available. • Chemical stabilization is easy to implement. • A vegetation/soil cover is adaptable to both fugitive dust and organic vapor emissions. • A wide variety of suitable plant species are available for vegetative stabilization. • Wet dust suppression can be used to minimize dust emissions during material loading to the waste pile as well as providing effective short-term control.	• Some chemical stabilization agents are expensive. • Vegetative stabilization may require treatment or soil covering of the waste pile before an effective cover can be achieved. • Vegetative stabilization will require some period of time to establish an effective cover. (Chemical stabilization may be used until the plants develop). • Wet dust suppression is effective only as a temporary measure. • Wet dust suppression may not be capable of achieving high efficiencies. • Actual efficiencies of physical and vegetative stabilization are unavailable. • Stabilization is generally not an effective control for vapor emissions.

(continued)

TABLE 8-1 (continued)

Advantages	Disadvantages
WINDSCREENS	
● Commercially available in many configurations. ● Simple in design and construction. ● Reduces wind speed over pile surfaces.	● Probably not effective in reducing emissions of small, "respirable" particles.
COVERS	
● Storage domes and synthetic membrane tension structures reduce particulate emissions to virtually zero. ● May be used as a gas collection system if designed to be air-tight and vented to a treatment system. ● Both may be used for active waste piles. ● Storage domes will retain their structural integrity for a long period of time. ● Storage domes are a widely used technology for material storage. ● Synthetic membranes are widely used at landfills.	● Installed costs are high. ● Tension structures may lose their structural integrity due to natural processes. ● Requires treatment system if used for volatile wastes.

(continued)

TABLE 8-1 (continued)

Advantages	Disadvantages
GAS EXTRACTION	
• May be effective in controlling organic vapor emissions. • Because the system is installed incrementally, it can be operated while the waste pile is still active. • Can be used in combination with other control technologies (e.g., tension structures, chemical stabilization). • Moderate cost.	• Does not control fugitive dust emissions. • May not achieve high removal efficiencies if used as sale control. • Requires treatment system. • Not a proven technology.
OPERATIONAL PRACTICES	
• Some changes cost little or nothing to implement (e.g., increasing operator awareness). • Telescopic chutes may be very cost-effective. • Some controls have experienced usage in the steel and crushed stone industries.	• No tests have been performed to determine the efficiencies of these controls. • Height-adjustable stackers and wind guards may be very expensive. • Changing slope, orientation, or surface area of a waste pile are not proven control methods. • These methods do not control organic vapor emissions.

STABILIZATION

Introduction

Stabilization is a means of decreasing fugitive dust (particulate) emissions from waste piles by minimizing the effects of wind erosion on the pile surface. Stabilization primarily affects particulate emissions, although in some cases it may act to decrease the emission of volatile organic chemicals as well. Stabilization techniques include dust suppression, chemical stabilization, and vegetative stabilization. Stabilization techniques have been used to control fugitive dust emissions from coal refuse piles, mineral refuse piles, metallic tailings piles, and solid wastes which are stored in piles. Stabilization, as a dust control method, has also been used on unpaved roads, process materials handling, and agricultural dust sources such as fields. In general, stabilization is considered to be easy to implement at an existing facility, and capable of effecting moderately high emission reduction. The costs involved in such systems range from being inexpensive to very expensive, depending on the system selected and the various constraints of the facility.

Description

Wet Dust Suppression--

Wet dust suppression involves the application of water or aqueous-based wetting agents on the waste pile. This technique serves to limit fugitive dust emissions by stabilizing dust particles in the pile via surface tension effected by moisture, thus reducing entrainment of particles as wind blows over the piles. Due to evaporation, wet dust suppression is a short-term control. It is necessary in most cases to maintain the moisture content at a certain level by frequent application of the wetting agent.

Water or wetting agents are usually applied by a spray truck or hose every few hours, although a facility may alternatively choose to install a permanent sprinkler system to service a pile or group of piles. A variety of wetting agents have been used, depending largely on the type of waste materials being stored. The wetting agents serve to enhance particle wetting, moisture spreading, and pile penetration, which can be key factors affecting the effectiveness of wet dust suppression as an emission control.

Wet dust suppression has found widespread usage as an emission control technique, largely due to the low cost and ease of implementing such systems. It can also be used to control dust emissions during pile loading, and material handling and transfer operations. The emission reduction effectiveness of dust suppression, however, is considered to be low (relative to other measures).

Chemical Stabilization--

Chemical stabilization is similar to wet dust suppression. This technique utilizes chemical binding materials, which, upon drying, bind with surface particles to form a protective crust. A wide variety of such chemical suppressants are commercially available including such agents as Orzan GL-50 (lignosulfate), Coherex (oil byproduct), Liquidow (calcium chloride), and SP-301 (synthetic polymer), to name a few.[1,2] These agents may be more effective on some wastes than on others.

Chemical stabilizers are usually applied in diluted form with spray equipment in a manner similar to using wet dust suppression. The major difference is that some chemical stabilizers may remain effective for periods of 6 months or longer, as opposed to only a few hours for wet dust suppression.[3] Additionally, the emission reduction effectiveness of chemical stabilization is much higher than that of wet dust suppression. The cost of such agents, however, is also much higher.

Vegetative Stabilization--

Vegetative stabilization involves covering of a waste pile with a layer of vegetation, such as grass. Vegetative stabilization is useful in the stabilization of a variety of surfaces and can be used in conjunction with other controls, such as chemical stabilization. A wide variety of plant species have been found to be effective at stabilizing different waste pile materials.[1] The main factor in reducing dust emissions from waste piles is achieving a uniform, high density plant cover. To that end, grasses such as rye, bluegrass, sorghum, and bromegrass may be effective.

Usually some modification to the waste pile surface must be made before effective stabilization can occur, such as the addition of topsoil, fertilization, pH modification, and/or slope reduction. Vegetative stabilization is restricted to inactive piles because of the time required to achieve an effective cover. To minimize dust emissions while the cover is developing, chemical stabilization agents may be applied.

Emission Reduction Efficiency

The available data on the control efficiency of wet dust suppression are minimal. Reported efficiencies are 30 percent for highly disturbed storage piles and 67 percent for nondisturbed storage piles,[1] but these results are very dependent on soil types, local climatic conditions, and frequency of application.

A study on dust control measures for active hazardous waste site cleanup indicates that water spraying of the working area of a front end loader and dumptruck resulted in a control efficiency of 42 percent for particles less than 30 micrometers in diameter, and 64 percent for particles smaller than 2.5 micrometers[5]. Control efficiency for less than 3- micrometer particles increased to 63 percent with the addition of Johnson-Marsh compound MR (a surfactant). Watering proved to be effective for only a few hours.

As part of the same study, dust was sprayed as it was being dumped from the front end loader into the dump truck.[5] This method was determined to be 50 percent efficient for particles smaller than 30 micrometers, and 56 percent for particles smaller than 2.5 micrometers.

Asa et al. found that some chemical stabilizers reduced asbestos emissions from roads paved with surfacing material containing serpentinite by 80 to 90 percent.[3] The study also found that stabilizers which formed a solid, water-resistant surface coating which bound road aggregates together retained better than 80 percent emission reduction after 6 months, despite vehicular traffic. Drehmel et al. found that the stabilizers they tested in the laboratory were generally 50 to 70 percent efficient.[2] The relative effectiveness of some of the chemicals they tested as represented by entrainment velocity are presented in Table 8-2. It can be seen that

TABLE 8-2. COST AND RELATIVE EFFECTIVENESS OF SOME CHEMICAL STABILIZATION AGENTS

Agent	Cost at recommended rate[b] ($/hectare)	Entrainment velocity[a] At manufacturer's recommended rate	At a cost of $750/hectare[b]
Coherex	1160	55	44
CPB-12	874	35	32
Lignosulfate	1136	61	61
Oil and water	2360	61	60
Pentron DC3	1647	44	30
Polyco 2151	168	48	50
SP-301	3020	55	21

Source: Drehmel et al., 1982 (Reference 2).

[a] Lowest wind velocity in mph to cause 10 gm/min reentrainment.

[b] February 1982 dollars.

lignosulfate and oil and water are probably the best dust control agents, based on wind tunnel data using coal dust.

Rosbury et al. have reported that the chemical stabilizers they tested were approximately 100 percent effective for 1 to 4 weeks, with declining control efficiencies thereafter.[5] Their results were based on actual field measurements of particle emissions generated from exposed soil plots.

The control efficiency of vegetative stabilization will vary considerably depending on the amount and type of cover on the pile. One report estimates a control efficiency between 50 and 80 percent for tailings piles, based on typical plant growth rates.[4] The same report estimates a 93 percent reduction in windblown emissions by using a combination of chemical and vegetative stabilization.[4] As mentioned earlier, the most important factor in reducing emissions is to achieve complete, high density plant cover. Efficiencies of 100 percent should be approached with careful construction of soil cover and vegetation, which would be applicable to nonsoil wastes. Such a cover system should also reduce organic vapor emissions substantially. Contaminated soil may not support a dense vegetation cover depending on the concentration and type of waste on it. In this case, the addition of a clean topsoil cover may be necessary.

Costs--

Costs for various chemical stabilization agents tested by Drehmel et al. are presented in Table 8-2. Also shown in Table 8-2 is a measure of relative cost-effectiveness, and the entrainment velocity at an application cost of $750/hectare (based on February 1982 dollars). It can be seen, for example, that although SP-301 is effective at the manufacturer's recommended application rate, it is not effective when applied at a lower cost of $750 per hectare. Lignosulfate, however, was equally effective at the recommended application rate and the lower application cost of $750/hectare. Polyco 2151, a synthetic copolymer manufactured by Borden, may be the most cost-effective agent, being effective at a cost of only $168 per hectare (about $190/hectare in March 1985 dollars).

Cost for wet dust suppression, physical stabilization, and vegetative stabilization were unavailable. Costs for wet dust suppression and physical stabilization are expected to be low, labor generally being the largest cost involved with implementation. Costs for vegetative stabilization may increase substantially if significant pile surface modifications or treatment are necessary in development of an effective cover.

WINDSCREENS

Introduction

Emissions from waste piles are impacted most significantly by the affects of prevailing winds. Winds blowing over waste piles generate fugitive dust emissions due to particle entrainment, and volatile organic compound emissions (when waste pile material is contaminated with VOC) by forced convection.

Windscreens are devices used at waste piles to act as a physical barrier to the wind. Windscreens have found widespread application at TSDF for waste pile control. Many designs have been developed. The designs used are similar to those described for the control of storage tanks (see Section 4), surface impoundments (Section 5), and landfills (Section 6).

Windscreens are considered to be capable of achieving moderate emission reductions. The costs of such systems are regarded as being relatively low, depending on the physical constraints of the waste pile.

Description

Waste pile windscreens are very much like the wind barriers described in previous sections (see above) for control of other TSDF processes. Typically, a windscreen is a simple wall or fence, extending either completely around the waste pile or placed in the direction of prevailing winds. The windscreens are all semiporous to wind, which is necessary because use of a solid wall would create a turbulent layer opposite the "wind side" which would decrease the wind reduction effectiveness.

A typical example of a waste pile windscreen is a "snow fence," i.e., a picket fence to which a porous synthetic membrane is attached. In installing a windscreen wind dispersal control of a waste pile, the following considerations are most significant:

- Height of windscreen. The barrier must be high enough to effect emission reductions (the higher the barrier, the greater the area of reduction effectiveness), but cannot be too high due to structural and cost considerations.
- Windscreen material. The type of material (system design) used may depend on weather, chemical, and operational activities of the facility.
- Operational considerations. The effect of a windscreen on the normal operation of a waste pile facility may determine its applicability.
- Orientation of windscreen. How the windscreen is set up relative to the wind pile has a bearing or emission reduction effectiveness. Constraints relative to orientation may therefore have an affect on the applicability of a certain system.

Emission Reduction Effectiveness

Several laboratory and field tests have been conducted to determine the effectiveness of windscreen control of waste piles. The results of the studies have indicated that the efficiencies of such systems may be as high as 80 percent, and in general are expected to be moderately high. The general results indicated, however, that the effectiveness of such systems is highly dependent on particle size, and, in fact, below a certain particle size may be ineffective. The studies also indicated that the effectiveness of waste pile windscreens depends upon the height of the barrier, distance from the pile, and orientation.

Soo et al. conducted wind tunnel tests to simulate the effectiveness wind barriers in reducing wind velocity over storage piles.[6] Preliminary results indicated that a barrier simulating a snow fence one-third the pile height with a wind porosity of 33 percent would reduce winds by 50 percent at a distance of three pile-heights away.

Drehmel et al. conducted tests on wind barriers with porosities of 50 and 65 percent. Wind speeds were reduced by 65 percent and 40 to 70 percent, respectively (depending on the location of the measurement).[2] The study also indicated that solid barriers provided no protection against wind entrainment at a storage pile due to increased turbulence.

A study conducted by Rosbury et al. has indicated that windscreens are only moderately effective on larger particles, and are ineffective on wastepiles consisting of small particles.[5] This study is considered to be of great validity due to its reliance on actual emissions measurements rather than modeling.

In general, windscreens are considered to be relatively effective, based on their widespread application. They would not be expected to be as effective as certain other measures, such as chemical suppression, but may be used on the basis of other facility constraints.

Costs

The installed costs of windscreens are dependent on materials and construction costs, only. No operating expenses are expected. A study by MITRE indicated a cost of from $2.00 to $2.70 per square foot of screen.[8] Another screen system, a 6-foot high polyester fence, was estimated to cost $14 per linear foot. Windscreens are relatively attractive due to their overall low cost, but the cost effectiveness of such systems is also considered to be low.

COVERS

Introduction

Covers serve to limit emissions of both particulate matter and volatile organic compounds by acting as a physical barrier to diffusion of vapors and to climatological forces such as solar irradiation, wind, and precipitation. Covers may be applied as a gas collection system, with vapors vented to a treatment system (e.g., carbon adsorber, afterburner). There are two primary cover designs in use at TSDFs, as follows:

- Storage domes; and
- Synthetic membranes (tension structures).

Waste pile covers are essentially identical to similar systems used to control emissions from surface impoundments (see Section 5), landfills (Section 6), and land treatment facilities (Section 7). They have found widespread application, due to the significant emission reductions they can effect, their strength and versatility, and relative ease of implementation at existing facilities. Costs of cover systems, however, are generally high.

Description

Waste pile covers are very similar to systems used to cover other TSDF processes (refer to sections as indicated above, for further detail). Since the control of particulate emissions is of much greater significance in waste pile covers, foam, liquid, or gaseous systems are not applicable. The most significant factors to consider in selecting and determining the applicability of a waste pile cover system are:

- pile size and shape;
- operating procedures including waste input and output rates and restrictions;
- waste material's chemical compatibility and vapor characteristics (e.g., permeability of cover); and
- durability of cover including strength, tear resistance, weather resistance, and chemical resistance.

Description

Storage Domes--

Storage domes are similar to the "beehives" used to store road salt. A typical wooden dome structure is supported on a reinforced concrete foundation wall, which may be 4 to 10 feet high. The waste rests on an asphalt pad about 4 inches thick. The domes may be filled to 85 percent of capacity using a front end loader.[8] If the dome is designed to be air-tight, the enclosed air may be vented to a treatment device to remove organic vapors which have volatilized from wastes present in the dome. A dome structure will provide effective emission control while the waste pile is still active, and is expected to have a long service life.

Synthetic Membrane Containment (Tension Structures)--

A synthetic membrane cover may be secured over a waste pile with tension cables, having the same function as a storage dome. If the membrane is constructed to form an air-tight seal around the foundation or asphalt pad, the structure may be vented to a gas treatment system. Square waste piles are more amenable to a membrane containment structure than are round piles, because they are easier to secure. An auger feed system can be installed as part of the structure to allow waste loading and unloading.[8] Tension structures may degrade over time due to natural processes such as photo-oxidation and drying, and thus, require regular inspection and maintenance.

Emission Reduction Effectiveness

Both storage domes and tension structures will reduce particulate emissions significantly. Assuming that some material may escape during loading into the dome or tension structures, achievable efficiencies should be between 95 and 100 percent. The effectiveness of such systems in the control of gaseous emissions will depend primarily on the ability of the dome or cover to capture and contain the vapors, because gas treatment technologies can exceed 95 percent removal efficiency. Collection efficiencies for domes are estimated to be about 92 percent.[9] Achievable efficiencies including treatment are probably in the range of 85 to 95 percent.

Emission control efficiencies for synthetic membrane containment will be the same as those described for synthetic landfill covers (see Section 6). Emissions through synthetic membranes from relatively undiluted organic wastes may be substantial over large areas.[10] However, if a forced-draft collection system is employed, vapor concentrations within the structure will remain low, minimizing emissions through the cover.

Costs

The installed costs of several different sizes of storage domes are presented in Table 8-3. These costs do not include expenditures for installation of electric wiring, lighting, ventilation, equipment, or treatment systems.

Installed costs of synthetic membrane tension structures range from $4.30 to $6.90 per square foot of pile surface area.[8] This estimate includes incorporation of the auger feed system mentioned earlier, but does not include treatment cost estimates.

GAS EXTRACTION

Introduction

Gas extraction technology has not been used on waste piles to control gaseous emissions, but it would be similar in construction to a landfill leachate collection system. Gas extraction as applied to landfills was proposed by SCS Engineers as a feasible technology which could be operated while a waste pile was still active.[9] It is not intended to control fugitive dust emissions.

Description

A gas extraction system consists of a network of screened pipes installed incrementally as each layer of waste is placed into the waste pile. The network is attached to a negative pressure fan or blower which draws gases and vapors from inside the waste pile and routes them to a treatment device such as an afterburner or carbon adsorber. In this manner, gases generated within the waste pile are withdrawn and treated before they can be emitted to the atmosphere. Gas extraction can thus occur while waste is still being placed into the pile, as well as after the pile is closed. This technology can be

TABLE 8-3. APPROXIMATE STORAGE DOME COSTS

Dome diameter (feet)	Capacity (tons)	Approximate cost
50	664	$ 49-50,000
61	1158	$ 50-53,000
72	1780	$ 61-64,000
82	2629	$ 70-74,000
100	4652	$ 85-89,000
116	6663	$103-108,000

Source: Vogel et al., 1983. (Reference 8).

used in combination with other control technologies such as storage domes or synthetic membrane tension structures to minimize fugitive dust as well.

Emission Reduction Efficiency

The collection efficiency of a gas extraction system has been estimated at between 70 and 90 percent, based on landfill gas control efficiency estimates. As mentioned earlier, no particulate emission reductions will be realized by installing a gas extraction system.

Costs

SCS has estimated that a gas extraction system with a carbon adsorption unit will cost about $17,000 for a 2,000-cubic foot waste pile, and about $40,000 for a 100,000-cubic foot waste pile.[9] These estimates do not include costs associated with construction of the waste pile itself, such as pad construction, buildings, and fences.

Domes and membrane tension structures may be more cost-effective than gas extraction systems because they offer control of fugitive dust as well as gaseous emissions.

CHANGES IN OPERATIONAL PRACTICES

Introduction

Changes in operational practices may result in significant reductions in emissions at little or no cost. This section will discuss the affect of changing the way waste is added to the pile, and changing the slope, orientation, and surface area of the pile. These changes will not have impact on gaseous emissions, but rather on fugitive dust emissions from waste piles.

Description

Changes in Waste Loading--

Reducing the fall distance of waste being dumped from front end loaders, overhead conveyors, clamshell buckets, or other equipment used for the formation and maintenance of waste piles will result in a decrease in fugitive dust emissions due to a lessening of impact forces. In some cases, this only requires increased awareness on the part of machine operators. In other cases, use of equipment such as height-adjustable loading equipment may be necessary. Such equipment allows for raising or lowering of the point of transfer of the waste to the pile, resulting in a consistently short fall distance.

Other methods for reducing dust emissions due to waste loading include the use of rock or stone ladders, telescoping chutes, lowering wells, and windguards.[11] Rock or stone ladders let material fall short distances in a step-like manner. By reversing the direction of travel on successive steps, momentum received from the previous fall, and thus the amount of fugitive dust generation, are reduced.

Telescoping chutes are enclosed, extendable tubes which carry material from the discharge point to the waste pile. This minimizes exposure of the waste to wind, and in so doing, minimizes dust emissions.

Lowering wells are perforated pipes projecting vertically out of the waste pile through which waste is added to the pile. Material added to the pile through the well flows out through the perforations, while dust generated due to the impact of falling is largely retained inside the pipe.

Wind guards are placed around the discharge end of a stacker arm, conveyor, telescoping chute, or other loading equipment to minimize wind action on dusts generated by falling waste. As was mentioned in the section on stabilization, water or water plus a wetting agent can be sprayed on the material as it is being transferred to further reduce dust emissions.

Changes in Slope, Orientation, or Surface Area--

A mathematical analysis of waste pile shape has shown that minimum surface area is exposed to the atmosphere when the angle of repose of the pile is 55°.[8] However, studies have shown that the slope and orientation of a pile is more important than surface area with regard to control of fugitive dust emissions. Slope of the pile in the prevailing wind direction should be less than 10 degrees, because measured up slope wind velocities accelerate substantially for slopes greater than this. Particulate entrainment is not necessarily proportional to wind speed, as discussed in the section on windscreens. Fine particles may be entrained in significant quantities even at low windspeeds.

Positioning the waste pile so that its length is perpendicular, as opposed to parallel, to the prevailing wind direction, may also reduce dust emissions.

Emission Reduction Effectiveness

Bohn et al. have estimated efficiencies for some of the controls discussed above.[11] All efficiencies depend on the operating practices in effect before the changes were made.

Height adjustable equipment was estimated to achieve a 25 percent reduction in fugitive dust emissions. Telescoping chutes were estimated to reduce emissions over previous conditions by 75 percent. Stone ladders and wind guards were estimated to achieve emission reductions of 80 percent and 50 percent, respectively. Stabilizing the material as it was transferred was estimated to result in a 75 percent control efficiency.

Positioning the length of a pile perpendicular to the prevailing wind direction can theoretically reduce dust emissions by 60 percent as compared to parallel positioning.[8]

Costs

Costs have been estimated for the above-mentioned control techniques as they are applied to iron and steel plants.[11] Initial 1977 costs for the controls are:

Control	Initial cost
Height-adjustable stacker	$150,000
Telescopic chutes	$ 10,500
Stone ladders	$ 30,000
Wind guards	$ 15,000
Spray systems	$ 90,000

Equipment designed for smaller operations such as those encountered at TSDFs is expected to cost less. Little or no cost should be associated with changing the slope, orientation, or the adjusting fall distances through increased awareness on the part of machine operators.

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